QUARTERLY TECHNICAL REPORT

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ELECTRIC THRUSTER POWER CONDITIONER

CONTRACT NO. 952297

HUGHES AIRCRAFT COMPANY
HUGHES DOCUMENT NO. 2228/1157

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ABSTRACT

Quarterly report on JPL Contract 952297 for a 20 CM Electric Thruster Power Conditioner and Support Equipment, describes progress in breadboard modification phase.

TABLE OF CONTENTS

INTRODUCTION

During the period between this and the last report, dated 30 September 1969, many changes in the system had been made and redirection of effort was accomplished to provide a system designed to meet the requirements imposed by a hollow cathode thruster. In the last three months, the breadboard model was returned to Hughes for modification from the oxide cathode design to the hollow cathode design. The work was performed under contract modifications 6, 8, and 10. Work on the breadboard was completed on 20 August 1970 and the unit was acceptance tested. The tests were passed and the unit shipped on 25 August 1970, one week prior to scheduled delivery.

BREADBOARD MODIFICATION

Modification of the breadboard model power conditioner to the hollow cathode configuration design is described herein and is designated as BB-1/M-1. The ground rules being used for this modification are that no changes will be made unless they are required to meet the electrical specification. Weight, efficiency and reliability will not be specifically considered except in those cases where the supply will be used directly in the experimental system.

The system being built is shown in Figure 1. The modules under modification or construction are listed below with the modifications to the units described in the corresponding sections:

1) Arc supply
2) Control module
3) Line regulator
4) 5 KHz inverter
5) Cathode modulator
6) Accelerator
7) Test console

With the increase in line voltage minimum to 53 volts a number of changes resulted. The line regulator output voltage was raised to decrease the load current caused by increased power delivered by the 5 KHz inverter. As a result, a source for 35 volts used for base drive in all the other inverters was added to the 5 KHz inverter. The old magnetic modulator and accelerator still requires 70 volts rms square wave for operation, so taps were added to the 5 KHz inverter output transformer while the cathode modulator obtains its drive directly from the collector-to-collector voltage. Some additional filtering was added in the 5 KHz inverter low voltage supplies. The accelerator output transformer was redesigned to operate at 49 volts input and one kilovolt output. The arc supply output transformer and filter was modified to the new requirements.

The test console loads are being modified in a fashion similar to the test console remaining at JPL.

The physical layout of the modules in the frame is shown in Figure 1. The arc rectifier filter has been moved to the position previously occupied by the cathode inverter. The arc output transformer is mounted in the space where the arc rectifier filter was and the cathode modulator replaces the accelerator line regulator. This arrangement physically locates the arc output transformer close to the inverter and rectifier filter module.

SECTION 1 - ARC SUPPLY

The arc inverter was modified to provide current limit by the addition of an amplifier that overrides the voltage regulator circuitry when the preset current is exceeded. The amplifier is connected to the anode of the reference zener (negative reference voltage) which sets the output voltage. As the output current as sensed in the rectifier-filter module reaches the control signal, the amplifier starts to raise the reference signal toward zero thus reducing the pulse width which holds the current constant for varying load resistance.

The amplifier gain was chosen to hold the output current to within one percent of full scale. The control signals were preset to 2.0 $\pm$ 0.09 amps at 0 volts and 9.0 $\pm$ 0.09 amperes at +5 volts in. The accompanying curves show load regulation for various input command voltages (Figure 2).

The rectifier-filter module was rebuilt to handle the higher current by changing the diodes to 30 ampere units and adding a new choke. The output transformer was also redesigned to take advantage of the higher input line voltages. By decreasing the turns ratio, the pulse width can be increased at low line and thus reduce the switching losses.

The regulation curves are shown in Figure 2, while the telemetry curves are given in Figures 3, 4, 5, and 6. Figures 7 and 8 show the voltage supplied by the arc supply prior to conditioning by the telemetry amplifier.

SECTION 2 - CONTROL MODULE

Modification of the control module includes the following:

1) Modification of the cathode control amplifier to a cathode vaporizer control amplifier.

2) Modification of the accelerator telemetry amplifier.

3) Modification of the arc voltage telemetry amplifier.

4) Rewire the internal, external reference switch to provide external arc control.

5) Modify the circuitry for on-off control of the cathode vaporizer.

6) Change the command wiring to the command memory relays K1 and K2 and utilize the contacts of K1 for a three command turn on sequence of power supplies.

7) Change the undervoltage set point.

Discussion of Changes

Item 1 - The amplifier, which was formerly used to control the cathode power, will be modified to the configuration shown in the drawing. This will provide the control function necessary to meet specification requirements.

The amplifier compares two input signals. One is the arc voltage reference, the other arc voltage represented by a 0 to +5 volt signal for 30 to 40 volts arc voltage. The feedback signal thus represents ½ volt per volt of arc voltage. The amplifier output controls the vaporizer controller which has a gain of two amperes for five volts input change. In order for the ΔI3/ΔE4 gain to be 6A/volt, the amplifier gain must therefore be 30 volts per volt:

$$A_{amp} = \frac{\text{Slope}}{A_{cont} \cdot A_{TM}} = \frac{6\ A/V}{\frac{2}{5}\ \frac{A}{V} \cdot \frac{1}{2}\ \frac{V}{V}} = 30$$

The bias voltage is then applied to the non-inverting side of the amplifier so that the cathode vaporizer current is not reduced until this preset level is higher than the feedback voltage.

Item 2 - The accelerator voltage telemetry amplifier will be modified to have the same gain but different bias point. The old requirement was a 0 to +5 volt signal for 1700 to 2100 volts, whereas the new requirement is 800 to 1200 volts. In both cases the ΔE is 400 volts.

Item 3 - The arc voltage telemetry amplifier requires modification due to the deletion of the arc current compensation in the arc inverter. This change was required to convert the circuit to a current limited supply. The unmodified amplifier was current compensated to take out the compensation added to the signal in the arc inverter. The new amplifier must now compensate in the opposite sense due to the drop in output voltage caused by losses in the output filter.

Item 4 - Switch S-1 previously switched the arc reference, which was fed into the cathode control amplifier, from an external source to the function generator. The switch now selects the same two inputs but feeds this signal to the arc power supply which contains the control amplifier.

Item 5 - If the option of the use of the "ON-I" command to start the Group I supplies (three instead of two groups) an on-off signal is required for the cathode vaporizer supply. This function is provided by a transistor which shorts the output of the amplifier and reduces the cathode vaporizer current to near zero.

Item 6 - A recent communication with JPL indicated the desire to break the power supplies into three groups. This can be done by rewiring relays K1 and K2 to reverse the input commands and move relay K2 to the on I position. Relay K2 then is wired to turn the two vaporizer supplies on with an "ON II" command.

Item 7 - A single resistor changes the voltage at which the power conditioner shuts off due to a drop in the solar panel voltage.

SECTION 3 - LINE REGULATOR

The basic 5 KHz line regulator required minor modifications for use in BB-1/M-1. Only the regulated output voltage was changed. Since system requirements now allow a minimum solar panel voltage of 53 volts, the regulated output voltage was changed from 35 volts to 49 volts. Resistor R16 was reselected for a 49 volt output voltage. Functionally, the line regulator supplies prime power to the accelerator inverter and drive and prime power to the 5 KHz inverter. Maximum steady-state load on the line regulator under this configuration is estimated to be 185 watts.

The current limit function provided by two amplifiers and a current sense resistor will be removed in the experimental units. The need for this limit arose due to redundancy of the 5 KHz inverter. Should a short have occurred in the Prime 5 KH inverter, the line regulator would have been lost. The experimental systems do not use a redundant 5 KHz inverter so this function is not required.

SECTION 4 - 5 KHz INVERTER

The 5 KHz inverter as used in BB-1/M-1 is a single inverter with prime and drive power supplied by the line regulator. The basic inverter is similar to that used before, however, the output configuration has changed. The primary of the output transformer has taps on each side of the center tap, resulting in an auto-transformer configuration. The taps provide 5 KHz drive power to the magnetic modulator and accelerator inverter at 70 volts peak. The primary winding provides drive power to the cathode modulator at 96 volts peak. A second winding supplies AC excitation to the arc current sense circuit. Three additional windings and their associated rectifier/filters provide the various DC housekeeping voltages. The $\pm$ 12 volts and $\pm$ 5 volt supplies are basically unmodified except LC filters have replaced capacitors on the outputs. A new winding has been added to the output transformer which, when combined with its rectifier/filter, provides 35 volts DC. The output of this supply is connected to the +35 volt distribution ring, thereby replacing the line regulator as a source of regulated 35 volt power.

SECTION 5 - CATHODE MODULATOR

The three new cathode supplies are being packaged into a separate module called the cathode modulator which will contain all the control circuitry and magnetics except the remote transformer for the cathode tip heater. The input power comes from the collector-to-collector voltage in the 5 KHz inverter at 96 volts peak.

The cathode tip heater is controlled by a digital "one" or "zero" supplied by external command. The +5 volt "one" signal turns Q3 on holding the reference signal at ground which sets the output at minimum current. The output current does not go to zero due to magnetizing current in the magamps. The output current is, however, held to a low value as can be seen in Figure 9. The regulator circuitry is almost identical to the magamp regulators in the magnetic modulator except for the use of orthonal material for magamp cores and the compensation networks. Orthonal has a much higher permeability per unit volume than the Hy-Mu 80 used previously and thus, the weight and volume is reduced. The regulation of the supplies is much improved by adding a diode, resistor and capacitor to the circuits used in the previous modulators.

The cathode keeper voltage telemetry is provided in a manner different from that provided in the neutralizer keeper due to the high voltage. A small, high voltage insulated transformer senses the AC voltage after the choke in the low voltage leg of the supply. The output is not linear due to the drops in the output rectifier as can be seen in Figure 10. Output current telemetry voltage versus output current is shown in Figure 11. Figue 12 shows the cathode keeper load lines.

A cathode vaporizer control curve is shown in Figure 13, while the telemetry curve for current is shown in Figure 14. The circuitry is nearly identical to that of the cathode tap heater.

SECTION 6 - ACCELERATOR SUPPLY (PS-6)

The accelerator supply is a single inverter delivering -1000 volts DC at a nominal current of 0.01 amps. A nominal steady-state power level of 10 watts yields stress levels well within the component's reliable operating range, thereby eliminating the need for a redundant inverter. No pulse-width-modulation or current/voltage feedback for output regulation is necessary because all input power is regulated and the output load varies between 5 and 10 mAmps typically. Drive power to the base of the output transistors is a 5 KHz regulated square-wave coming from the 5 KHz inverter. Prime power to the center tap of output transformer is a regulated 49 volts from the line regulator. Maximum output power demands of approximately 50 mAmps can be supplied with derated performance.

A +5 volt signal from the control module grounds the center-tap of the drive transformer through a transistor and allows the inverter to operate. When the control signal drops to 0 volts, transistor turns off, opening the ground return to the drive transformer, and the inverter turns off. Status of the control signal is dependent on either the command mode or overload trip as determined by the control module.

The change in this module is the output transformer only. This module is the newly designed unit supplied to JPL during integration testing. The load regulation curve is shown in Figure 15 and the voltage and current telemetry curves are shown in Figures 16 and 17, respectively.

SECTION 7 - TEST CONSOLE

1) Control Panel - Failure mode of the 5 KC, cathode, and arc inverters has been deleted.

   The following additional circuits have been added:

   A 2.4 KC start inverter (see schematic).

   An arc reference voltage of 0-5 volts. A zener reference variable supply.

   Cathode tip heater control, 0 or 5 volts. A zener reference, 5 volts or off.

   Provisions for monitoring the additional power conditioner supplies and TM channels.

2) Command Generator (no change)

3) Telemetry Panel - Added telemetry readout for V9 current, V10 voltage, and V10 current.

4) DC power is the same except power supplies are not all connected in parallel for low voltage (40V or less).

5) Arc Test (same).

6) Meter Enabling Circuit - This circuit operates the same but now controls magnet (V1), vaporizer cathode (V3), arc (V4), cathode tip heater (V9), and cathode keeper (V10). Meter enabling circuit does not control the AC current readings since these are not at high voltage.

7) Magnet Load (V1) - same

8) Vaporizer Load (V2) (same)

9) Vaporizer Cathode (V3) - This load is the same as V2, above, except all components and wiring are insulated for high voltage.

10) Arc Load (V4) - This load is the same except for the value of the loads. The loads selected by JPL are used, and are:

    Open
    Min - 12 to 48
    2 - 8.6 to 18.4
    3 - 4.5 to 6.1
    Max - 3.53 to 4.5

11) Screen Load (V5) - (same)

12) Accelerator Load (V6) - This circuit is the same but the loads have been changed as follows:

    Open
    Min - 195K + 10K variable
    2 - 95K + 10K variable
    3 - 70K + 10K variable
    Max - 20K + 10K variable

13) Neutralizer Heater Load (V7) - Same, except power conditioner output transformer is located in the test console.

14) Neutralizer Keeper (V8) - (same)

15) Cathode Tip Heater (V9) - Same circuit as used by JPL. The power conditioner output transformer is located in the test console. The load can be open circuited and it can be short circuited by the arc/short switches. The load is variable from 1 to 3.5.

16) Cathode Keeper (V10) - The load is normally connected to the common connection at the screen load through the meter enable circuit. The load can be open circuited and it can be short circuited by the arc/short switches. The load is 60K or a variable load of from 10 to 60.

17) Status Panel - (same)

BREADBOARD ACCEPTANCE TEST

The results of the acceptance test are tabulated in the appendix.

EXPERIMENTAL UNITS

Physical Design and Assembly

Physical design and drafting of the experimental system is progressing satisfactorily and will be completed during the month of September. Most physical designs and assembly drawings and all schematics will be ready for the design review scheduled 1 September 1970. Assembly of the screen inverter modules has begun with the other modules to follow as soon as chassis parts become available.

Transistors

Transitron transistors have been placed on order which have isolated collectors. The use of this modified TO-61 package will save weight and increase the reliability of operation by lowering the junction temperatures due to lower thermal resistance to the heatsink. The units to be delivered must meet the specification attached as Appendix II. The test circuit will be physically supplied to Transitron by Hughes so that there should be no doubt about correlation of measurements of switching times. The units should be much faster than any delivered to date in that off-the-shelf units purchased by Hughes on another contract switch typically in ½ microsecond.

The Dow-Corning R62047 called out is to protect the transistor chip from shorts caused by weld splatter common in isolated collector units. The splatter occurs randomly and the transistor shorts only appear during random vibration. The process of using the R62047 is used by Solitron for their isolated collector package and was recommended by Hughes Components and Materials Department for use in the Transitron units.

Weight Analysis

The weight reduction study is a continuing process during which each step of assembly is used to hold weight down. A thermal study showed that transistor mounting cups were poorer thermally than bonding the small transistor cases, top down to the metal plates by using epoxy. This was true even when a thin insulator was used between the plate and chassis. The removal of these cups from the system indicates a weight savings of over one-half pound. The use of 600 volt insulated teflon wire as opposed to 1000 volt insulation will save two-tenths of a pound for the return wires only.

Efficiency Analysis

The efficiency of the arc supply delivered on the breadboard unit appears to be about eighty-six percent. The use of Transitron transistors should increase this to about eighty-eight percent or two percent less than the expected. This should be more than offset by the faster than anticipated switching speeds of the new transistors as used in the screen supply. Efficiency measurements using the slower Transitron units indicate an efficiency of 92% for the screen system.

APPENDIX I

BREADBOARD ACCEPTANCE TEST DATA

POWER SUPPLY NO. 1 - MAGNET/MANIFOLD HEATER

ITEMS	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} (nom.)	13.0 volts	10.40	10.35	10.35		
I_{out} (nom.)	0.6 amps	.5820	.5820	.5815		
TM I_{out} (nom.)		---	---	---		
P_{out} (nom)	(13 x 0.6) 8 watts	5.75	5.75	5.75		
% Regulation	$\pm$ 1% (12 ma)	OK	OK	OK		
E ripple (peak)	5% 30 ma					
I Limit	0.6 amp + 10%	.1400	.1400	.1400		
E ripple + noise	---	---	---	---		

POWER SUPPLY NO. 2 - MAIN VAPORIZER

ITEMS	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} (max)	10.0 volts	8.88	8.89	8.90		
I_{out} (max)	2.0 amps	2.08	2.08	2.08		
TM I_{out} (max)	See Curve	---	---	---		
% Regulation (I)	$\pm$ 5% (100 ma)					
I limit	2.0 amps + 10%	2.22	2.22	2.22		

POWER SUPPLY NO. 3 - CATHODE VAPORIZER

ITEMS	SPECIFIED VALUE	MEASURED VALUE			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} (max)	10.0V at 2A	10.15 at PC	10.15	10.15		
I_{out}	2.0 amps at 10V	---	---	---		
TM I_{out}	See Curve	---	---	---		
% Regulation	±5% 200 ma	2.01	2.01	2.01		
I (limit)	2.0 amps + 10%	1.78	1.84	1.85		

POWER SUPPLY NO. 4 - ARC SUPPLY

ITEM	SPECIFIED VALUE	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} at NL	60V	73.3	81.5	102.5		
20ma		51.0	57.1	76.4		
50 ma		48.9	54.8	70.8		
E_{out} at 2 amps	37.0 volts	41.3	41.2	41.3		
3 amps		41.0	41.0	40.9		
4 amps		40.7	40.7	40.6		
5 amps		40.1	40.0	40.3		
6 amps		40.0	39.8	40.1		
7 amps		39.6	39.5	39.9		
8 amps		39.4	39.3	39.8		
9 amps		34.9	35.3	35.8		
I Reg. Ref 0.0	± 1% 180 ma	1.92	1.89	1.90	≈ 40V	
0.0		2.47	2.47	2.44	≈ 10V	
1.0		2.45	3.3	3.30	≈ 40V	
1.0		3.58	3.6	3.62	≈ 15V	
2.0		4.50	4.44	4.51	≈ 40V	
2.0		4.90	4.91	4.89	≈ 20V	
3.0		---	6.01	6.01	≈ 35V	
3.0		---	6.23	6.22	≈ 25V	
4.0		7.28	7.28	7.25	≈ 40V	
4.0		7.56	7.54	7.55	≈ 30V	
5.0		8.67	8.67	8.68	≈ 40V	
5.0		8.9	8.93	8.93	≈ 35V	
I (max)	10 amps	9.50	9.55	9.60		
(I arc + I Screen)		8.92	8.95	8.94		
I limit	10 amp + 10%	9.95	9.95	10.00		

POWER SUPPLY NO. 4 - ARC SUPPLY (Continued)

ITEM	SPECIFIED VALUE	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
Iripple	2% - 180 ma	@9 amp 60ma p-p @2 amp 100ma p-p	@9 amp 60ma pp @2amp 50ma p-p	@9 amp 50ma p-p @2 amp 60ma p-p		
E(ripple + noise)	---	@2amp 2V p-p				
TM Out (max)	See Curve	@ 9 A 1V p-p				

POWER SUPPLY NO. 5 - BEAM SUPPLY

ITEM	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E out N.L.	2200V	2080 2070	2080 2040	2080 2090		
Eout (nom)	2000V	2100	2110	2111		
I out (nom)	1 amp	1	1	1		
TM E out (nom)	See Curve	---	---	---		
TM I out (nom)	See Curve	---	---	---		
% Regulation	± 1% 40 volt					
E ripple peak	5% 100 volt	50	60	80		
E ripple + noise	---	---	---	---		
I trip	1.1 amps	1.068	1.06	1.065		

POWER SUPPLY NO. 6 - ACCELERATOR

ITEM	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} (N.L.)	1100 volts	1190	1230	1230		
E_{out} (nominal)	1000 volts	1120 1095	1120 1090	1118 1090		
I_{out} (nominal)	10 ma	11	11	11		
TM E_{out} (nom.)	See curve	---	---	---		
TM I_{out} (Nom.)	See Curve	---	---	---		
T Regulation	$\pm$ 1% 22 volts					
E_{ripple} (peak)	5% 50 volts	15	20	20		
$E_{ripple + noise}$	---	---	---	---		
I_{trip}	50 ma	---	---	---		

POWER SUPPLY NO. 7 - NEUTRALIZER HEATER

ITEM	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} (max)	12V	12.4	12.4	12.4		
I_{out} (max)	3.4 amps	3.43	3.43	3.43		
TM I_{out} (max)		---	---	---		
% Regulation	$\pm$5% 340 ma	OK	OK	OK		
I (limit)	3.4 amp + 10%	3.72	3.72	3.72		

POWER SUPPLY NO. 8 - NEUTRALIZER KEEPER

ITEM	SPECIFIED VALUE	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} at 5 ma	300 volt	297.0	298.0	298.0		
E_{out} at 20 ma	---	32.5	32.6	32.8		
E_{out} at 50 ma	---	29.4	29.5	29.6		
E_{out} at 100 ma	---	27.9	28.0	28.0		
E_{out} at 200 ma	---	23.5	23.6	23.6		
E_{out} at 300 ma	---	18.4	18.5	18.6		
E_{out} at 400 ma	---	12.7	12.9	12.9		
E_{out} (nom.)@500ma	10 V	5.0	5.17	5.35		
TM E_{out} (nom)	See curve	---	---	---		
TM I_{out} (nom)	See curve	---	---	---		
E_{ripple} (peak)	5% 50 mv					
$E_{ripple + noise}$	---					
I (limit)	600 ma + 10%	500	500	500		

POWER SUPPLY NO. 9 - CATHODE HEATER

ITEM	SPECIFIED VALUES	MEASURED VALUES 53	60	80	COMMENTS ACCEPT	REJECT
E_{out} (nom)	8.5 volt	8.5	8.5	8.5		
I_{out} (nom)	4.8 amps	4.8	4.8	4.8		
TM I_{out} (nom)	See curve	---	---	---		
% Regulation	$\pm$ 5% 480 ma	OK	OK	OK		
I limit	4.8 amp + 10%	4.73	4.73	4.73		

POWER SUPPLY NO. 10 - CATHODE KEEPER

ITEM	SPECIFIED VALUES	MEASURED VALUES			COMMENTS	
		53V	60V	80V	ACCEPT	REJECT
E_{out} @ 0 ma		39.5V				
E_{out} @ 5 ma	300 v min	290	292	293		
E_{out} @ 20 ma		30.5	30.8	30.8		
E_{out} @ 100 ma		26.9	27.0	27.0		
E_{out} @ 200 ma		23.8	24.1	24.1		
E_{out} @ 300 ma		20.7	21.0	21.0		
E_{out} @ 400 ma		17.3	17.5	17.5		
E_{out}(nom)@500 ma	10V	13.5	13.5	13.5		
$E_{ripple\ peak}$	2% 20 mv	400	400	400		
$E_{ripple\ +\ noise}$	---	---	---	---		
I (limit)	600 ma + 10%	730	730	730		

CONTROL LOOP CHARACTERISTICS E LINE ≈ 53 volts

MAIN VAPORIZER/BEAM

I_5 REF	I = I2 MAX		I = I2 MIN		ΔI5	ΔI2	LOOP GAIN
	I5	I2	I5	I2			ΔI2/ΔI5
0.00 volts	.484	1.77	.502	≈ 0.0	.018	1.77	98.1
1.00 volts							
2.00 volts	.682	1.75	.697	≈ 0.0	.015	1.75	113
3.00 volts	.781	1.74	.795	≈ 0.0	.014	1.74	124
4.00 volts							
5.00 volts	.982	1.72	.995	≈ 0.0	.013	1.72	132

H.C. VAPORIZER/ARC

E4 REF	I3 UPPER KNEE			I3 LOWER KNEE			ΔE4	ΔI3	LOOP GAIN
	E4	I4	I3	E4	I4	I3			ΔI3/ΔE4
0.00 volts	35.6	2.12	1.90	35.2	2.13	0.0	0.4	1.90	
1.00 Volts	35.7	3.37	1.95	35.3	3.37	0.0	0.4	1.95	
2.00 volts	35.3	4.68	1.90	34.9	4.69	0.0	0.4	1.90	
3.00 volts	35.5	6.04	1.98	35.0	6.05	0.0	0.5	1.98	
4.00 volts	35.6	7.41	1.90	35.2	7.48	0.0	0.4	1.90	
5.00 volts	35.7	8.84	1.90	35.1	8.91	0.0	0.6	1.90	

CONTROL LOOP CHARACTERISTICS E LINE = 80 volts

MAIN VAPORIZER/BEAM

I5 REF	I = I2 MAX		I = I2 MIN		ΔI5	ΔI2	LOOP GAIN
	I5	I2	I5	I2			ΔI2/ΔI5
0.00 volts	.483	1.74	.503	≈ 0.0	.020	1.74	
1.00 volts							
2.00 volts	.678	1.74	.693	≈ 0.0	.015	1.74	
3.00 volts	.772	1.83	.795	≈ 0.0	.023	1.74	
4.00 volts							
5.00 volts	.978	1.73	.993	≈ 0.0	.015	1.73	

H.C. VAPORIZER/ARC

E4 REF	I3 UPPER KNEE			I3 LOWER KNEE			ΔE4	ΔI3	LOOP GAIN
	E4	I4	I3	E4	I4	I3			ΔI3/ΔE4
0.00 volts	35.9	2.10	2.0	35.1	2.11	0.0	0.8	2.00	
1.00 volts	35.6	3.35	1.93	35.1	3.35	0.0	0.5	1.93	
2.00 volts	35.6	4.68	1.99	35.0	4.68	0.0	0.6	1.99	
3.00 volts	35.5	6.05	1.90	35.1	6.05	0.0	0.4	1.90	
4.00 volts	35.8	7.48	2.00	35.2	7.48	0.0	0.6	2.00	
5.00 volts	35.9	8.97	1.90	35.5	8.97	0.0	0.4	1.90	

APPENDIX 2

D. R. Garth
20 July 1970

TRANSISTOR SPECIFICATION

ST18037-2

Description - This specification covers a silicon, NPN, power transistor intended for inverter applications. The device is generally suitable for use in high-reliability space environments.

Maximum Ratings

Collector to Base Breakdown Voltage	BVCBO	325V
Collector to Emitter Breakdown Voltage	BVCEO	325V
Emitter to Base Breakdown Voltage	BVBEO	12V
Collector Current	IC	20A
Base Current	IB	5A
Total Power Dissipation at $T_C = 100^\circ C$	PT	67 W
Junction Temperature	Tj	-65 to 200°C
Storage Temperature	TSTg	-65 to 200°C
Thermal Resistance	θJ-C	1.50°C/W

Physical Description - Isolated TO-61 JEDEC registered case. Collector isolated from case.

Electrical Requirements

TEST	CONDITIONS	LIMITS AT 25°C	TEST METHOD*
BVCBO	IC = 100μA, IE = 0	325V min.	3001
BVEBO	IE = 100 μA, IC = 0	12 V min.	3026
BVCEO	IC = 30 mA, IB = 0	325V min.	3011
ICBO	VCB = 275V, IE = 0	10 μA max.	3036
ICEO	VCE = 275V, IB = 0	50 μA max.	3041
$VBE_{(SAT)}$	IC = 10A, IB = 1A	1.2V max.	3066
$VCE_{(SAT)1}$	IC = 8A, IB = 0.8A	500 mv max.	3071
$VCE_{(SAT)2}$	IC = 10A, IB = 1.0A	700 mv max.	3071
h_{FE1}	VCE = 5V, IC = 2A	50 min 150 max	3076 3076
h_{FE2}	VCE=5V, IC = 10A	15 min.	3076
h_{FE3}	VCE = 5V, IC = 20A	8 min.	3076
$\frac{tr+tf}{2}$	IC = 8A, IB1 = IB2 = 800m A	0.7 μs max.	Per Fig. 1
tf + 0.6 $VCE_{(SAT)}$	IC = 8A, IB1 = IB2 = 800m A (tf2 is Ic rise time in μs and $VCE_{(SAT)}$ in volts)	1.0 max.	Per Fig. 1
t_{SAT}	IC = 8A, IB1 = IB2 = 800 m A	2.0 μs max.	Per Figs. 1 & 2
$t_{storage}$	Ic = 8A, IB1 = IB2 = 800 mA	1.0 μs max.	Per Fig. 1

*Per MIL-STD-750

1) The electrical requirements specifications listed herein shall be tested for at the manufacturer on a 100% basis.

2) The unit shall be capable of withstanding a stud torque of 15 inch-pounds maximum.

3) The safe operating area is as shown in Figure 3.

4) The part number ST18037 shall be clearly marked on the part and serialized. Manufacturer's test data must accompany each lot.

5) Typical transistor parameters must have the same type of characteristics as shown in Figure 4.

6) Parts not complying to this specification as measured by Hughes shall be returned to the manufacturer for refund or replacement. The test methods used by Hughes shall be mutually agreed upon by Hughes and the supplier.

7) The power derating curve is given in Figure 5.

8) The die must be coated with Dow-Corning R62047 to prevent shorting of the unit by weld splatter.

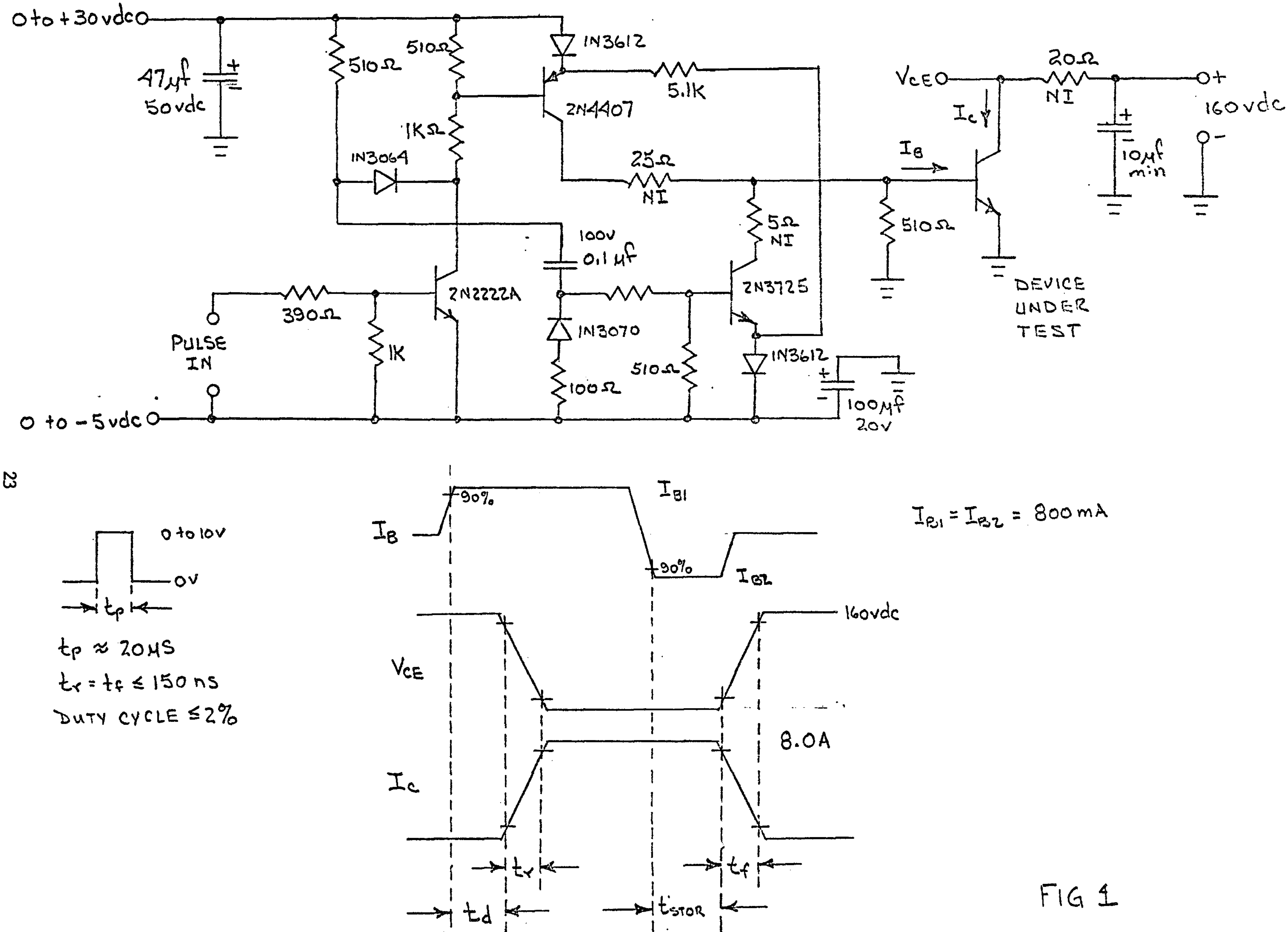


FIG 1

ST18037-2

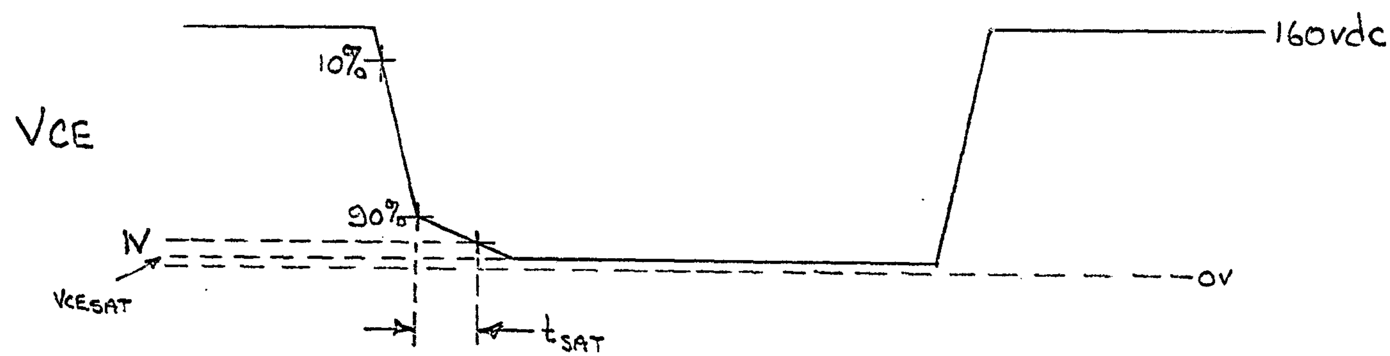


FIGURE 2

ST18037-2

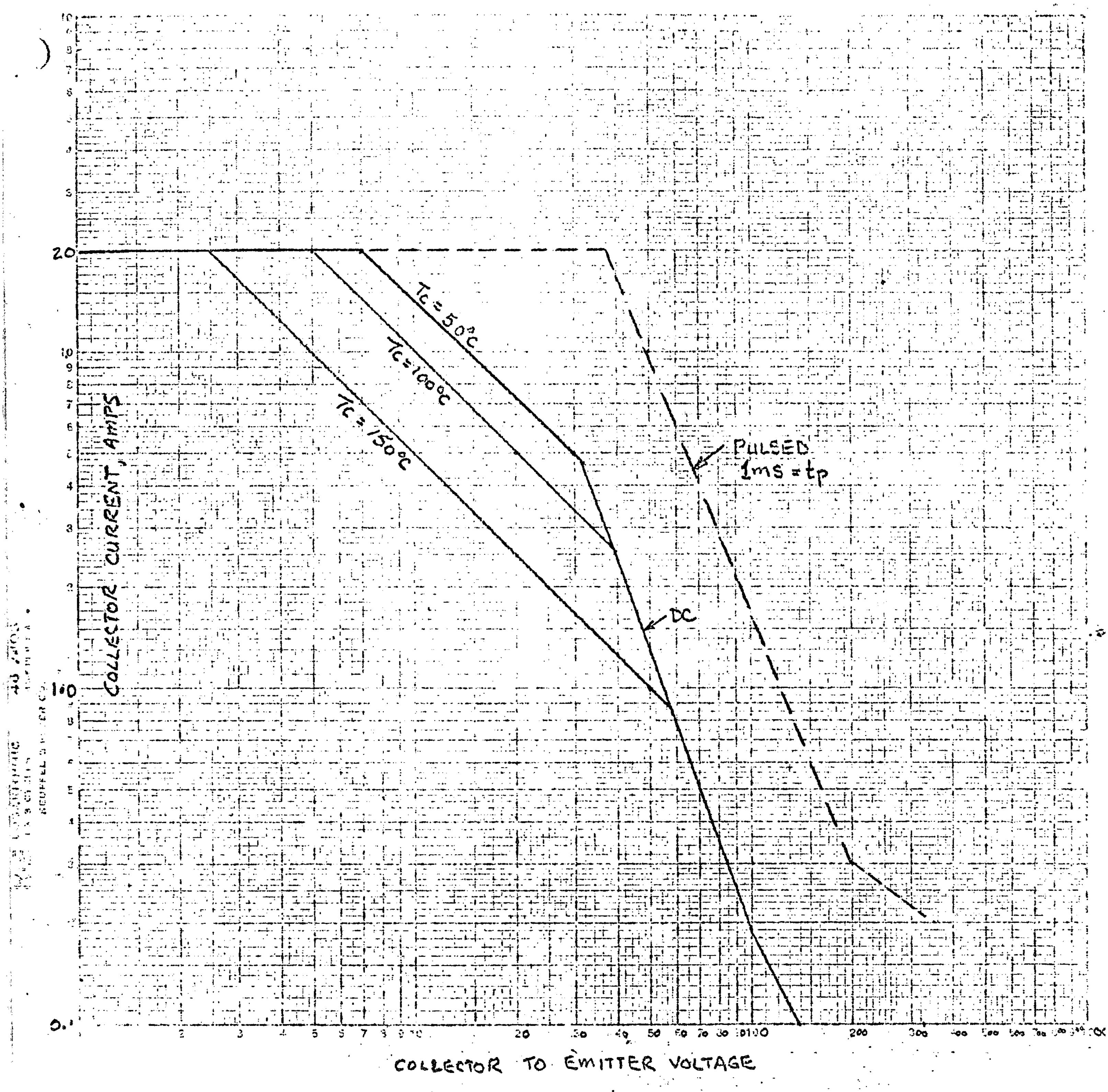
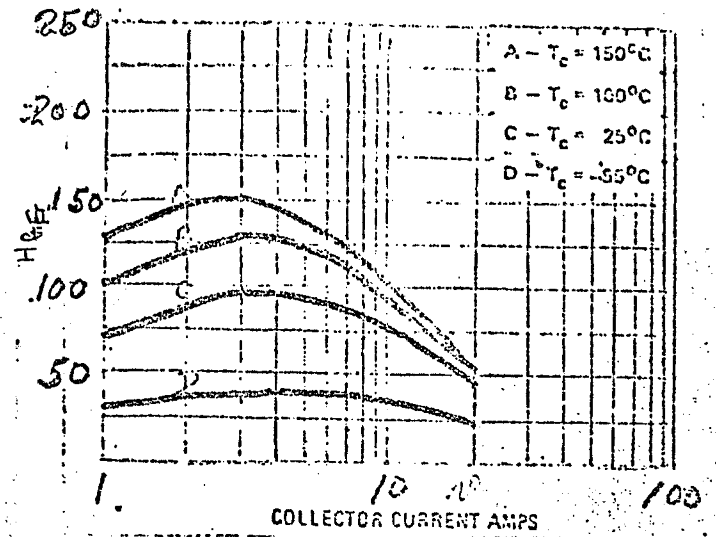


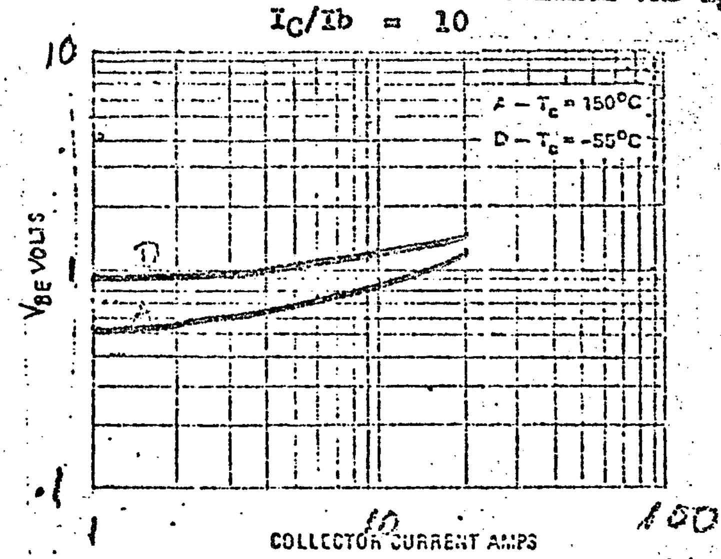
FIGURE 3

SAFE OPERATING REGION

TYPICAL CHARACTERISTICS
STATIC FORWARD CURRENT TRANSFER RATIO
RATIO VRS COLLECTOR CURRENT



BASE TO EMITTER SATURATION VOLTAGE VRS I_C
I_C/I_b = 10



COLLECTOR TO EMITTER SATURATION VOLTAGE VRS I_C
I_C/I_b = 10

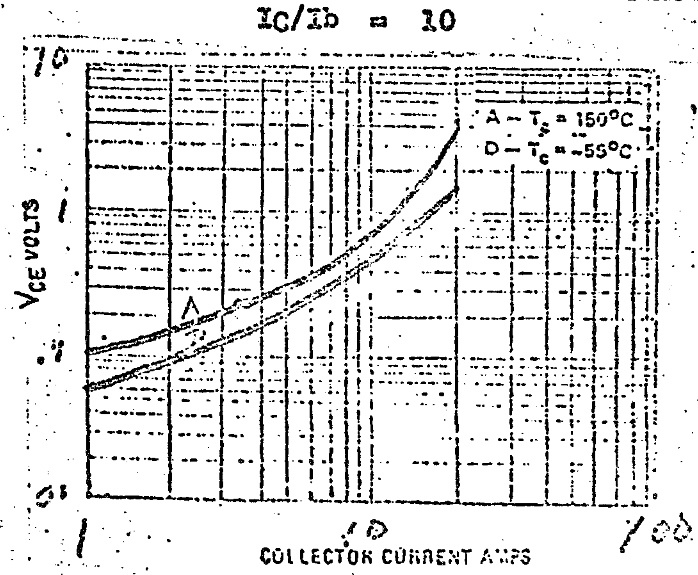


FIGURE 4

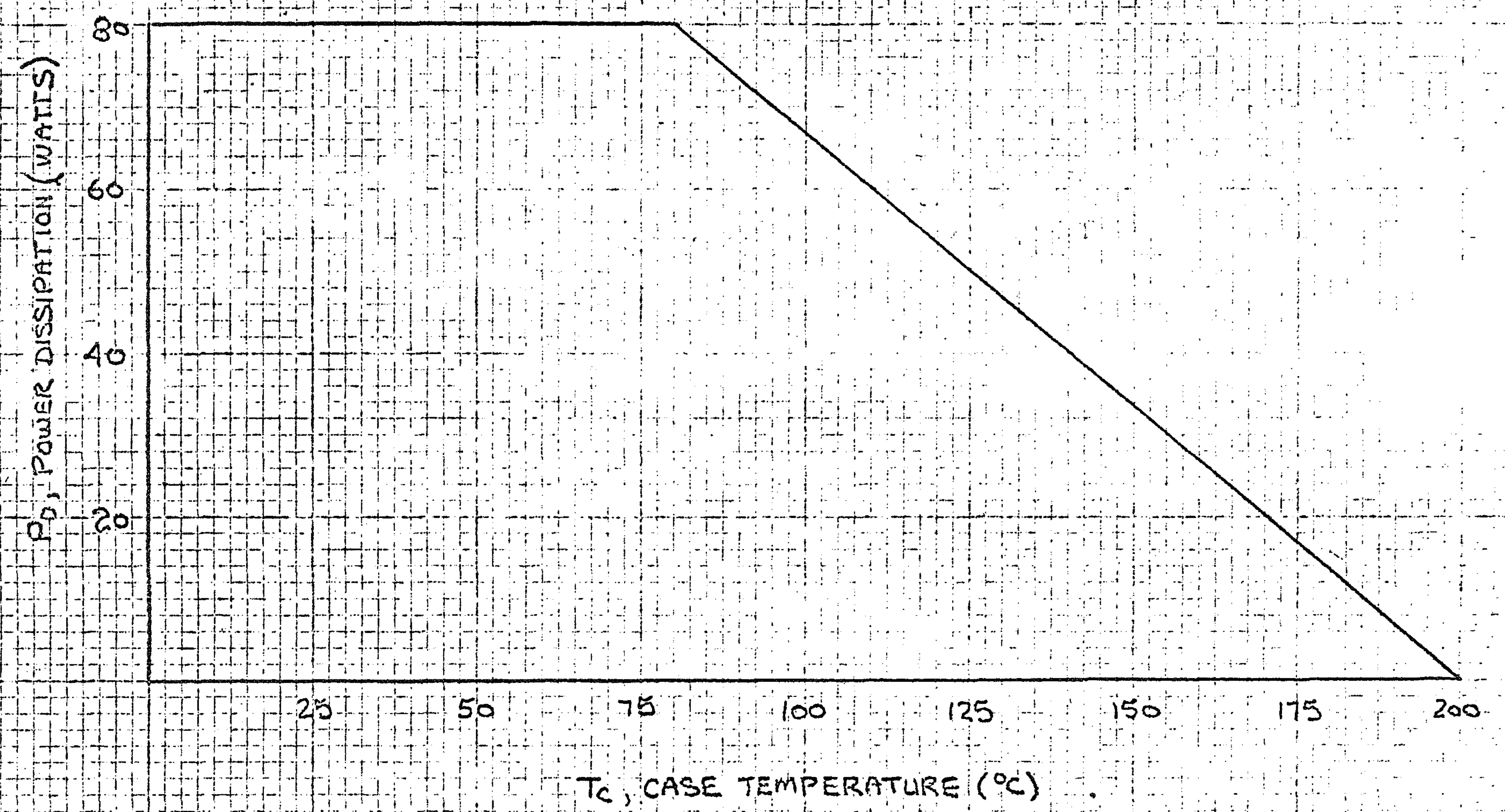


FIGURE 5

POWER DERATING CURVE ST18037-2

BACKSIDE VIEW OF

BB-1/M-1 SYSTEM LAYOUT

4 SCREEN INV	3 SCREEN INV	2 SCREEN INV	1 SCREEN INV
8 SCREEN INV	7 SCREEN INV	6 SCREEN INV	5 SCREEN INV
12 5KHz	11 ACCEL INV	10 ARC INV (PRIME & STBY)	9 ARC RECTIFIER FILTER
16 CONTROL MODULE	15 LINE REG	14 ARC OUTPUT XFMR MOD	13 H.V. FILTER MOD
20 DIGITAL STAGGERED PHASE GEN	19 CATH MOD CATH VAP CATH HTR CATH KPR	18 MAG MOD MAG MAIN VAP NEUT HTR NEUT KPR	17 H.V. CONNECTOR MOD

FIG. 1

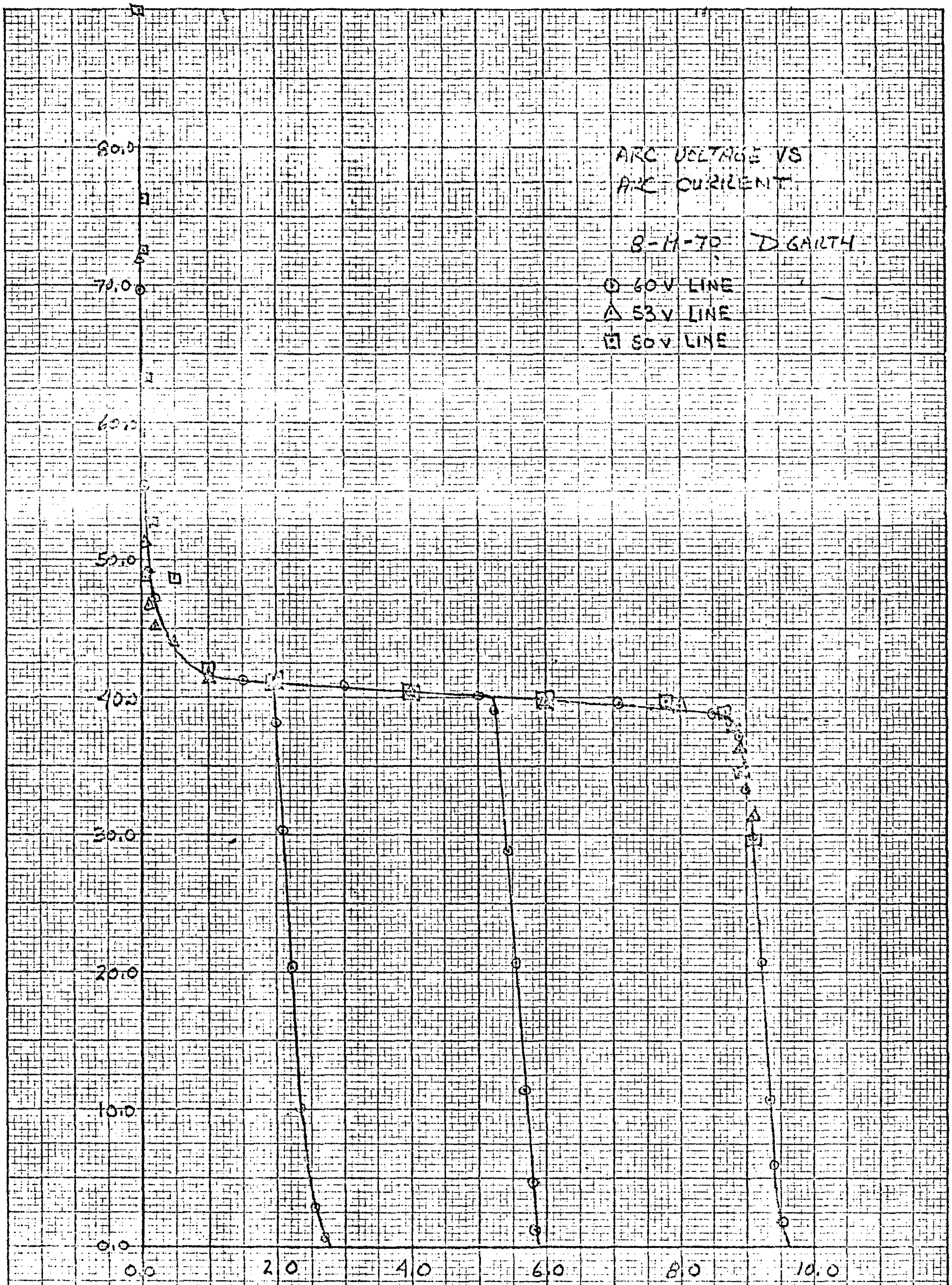

ARC VOLTAGE VS
ARC CURRENT
8-11-70 D GARTH
60 V LINE
53 V LINE
50 V LINE
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0

fig 2

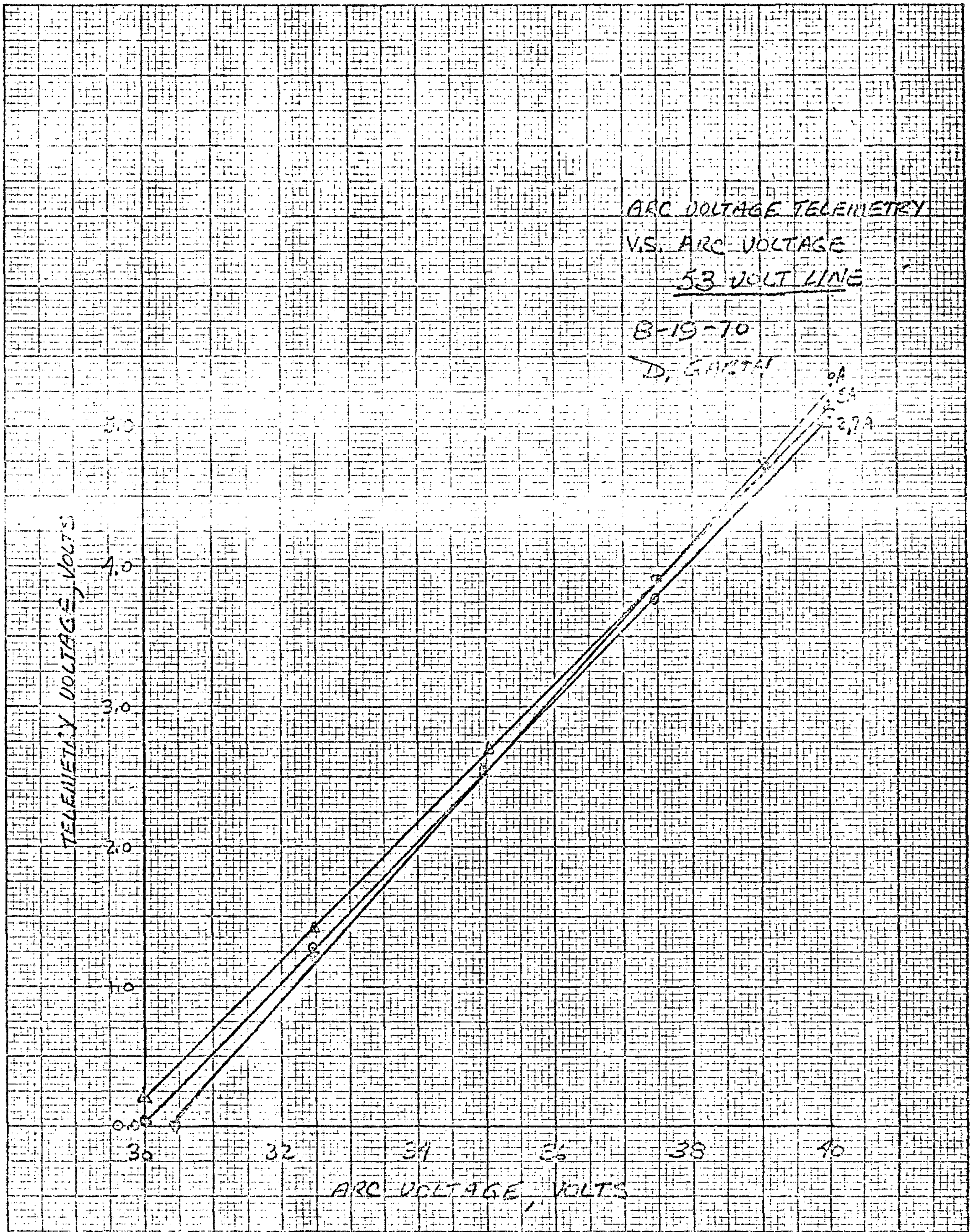

ARC VOLTAGE TELEMETRY
V.S. ARC VOLTAGE
53 VOLT LINE
8-19-70
D. SMITH
0A
5A
2.7A
TELEMETRY VOLTAGE, VOLTS
5.0
4.0
3.0
2.0
1.0
0.0
30
32
34
36
38
40
ARC VOLTAGE, VOLTS

Fig 3

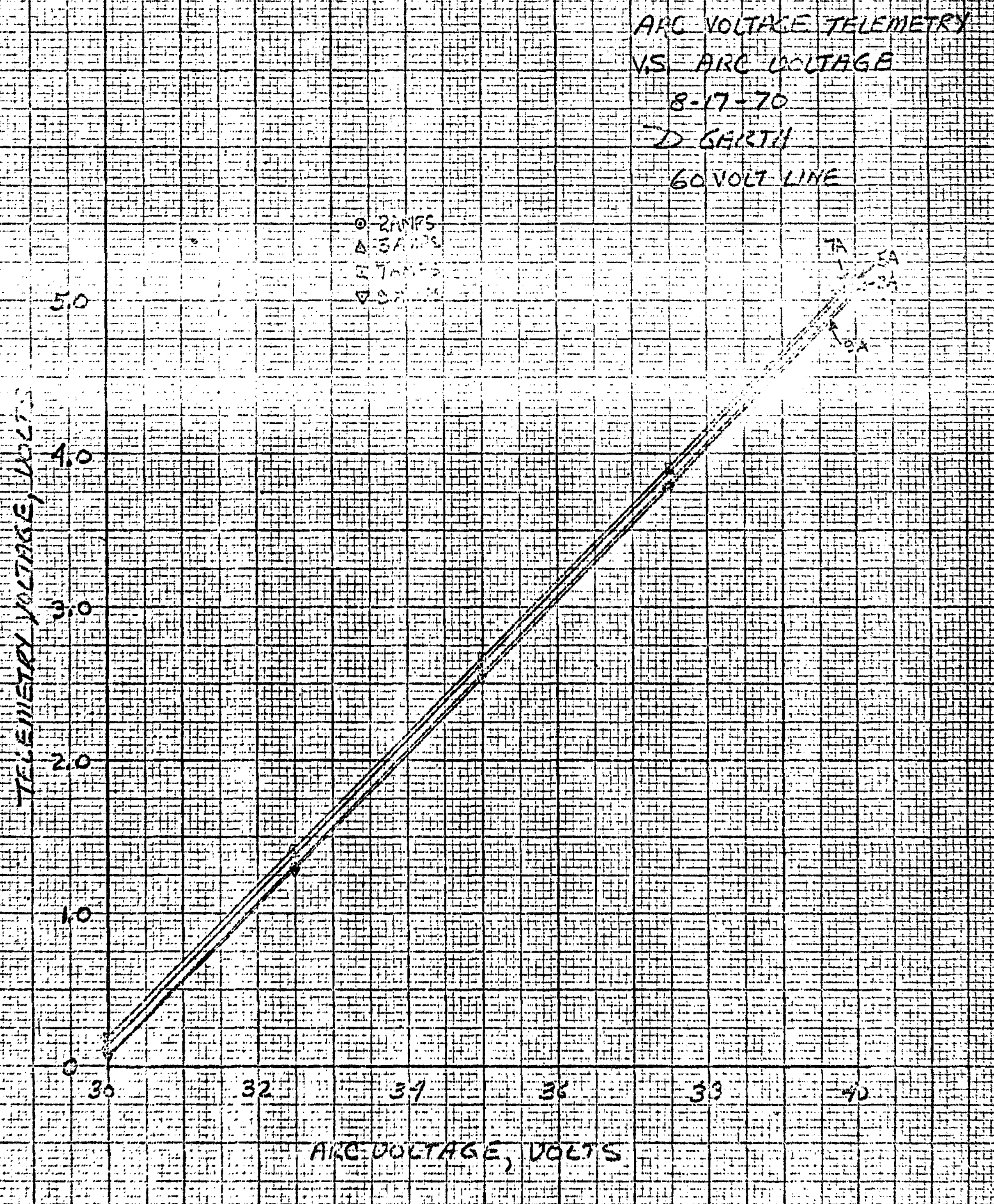
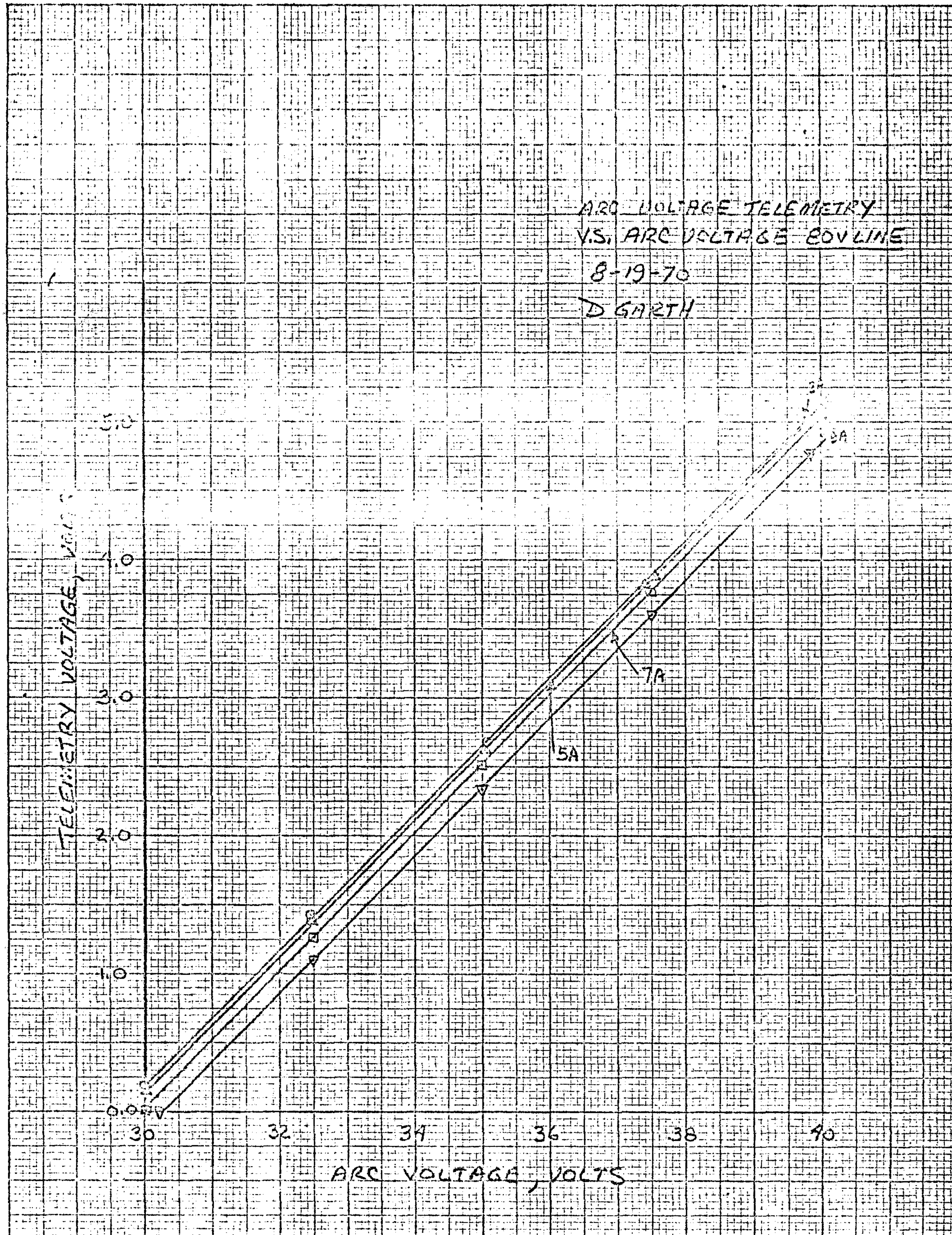

ARC VOLTAGE TELEMETRY
VS. ARC VOLTAGE
8-17-70
D GARTH
60 VOLT LINE
TELEMETRY VOLTAGE, VOLTS
ARC VOLTAGE, VOLTS
0
1.0
2.0
3.0
4.0
5.0
30
32
34
36
38
40

fig 4



ARC VOLTAGE TELEMETRY
V.S. ARC VOLTAGE 80V LINE
8-19-70
D GARTH
5.0
4.0
3.0
2.0
1.0
0.0
30
32
34
36
38
40
TELEMETRY VOLTAGE, VOLTS
ARC VOLTAGE, VOLTS
3A
7A
5A

fig 5

K+E 10 X 10 TO ½ INCH 46 1320
7 X 10 INCHES MADE IN U.S.A.
KEUFFEL & ESSER CO.

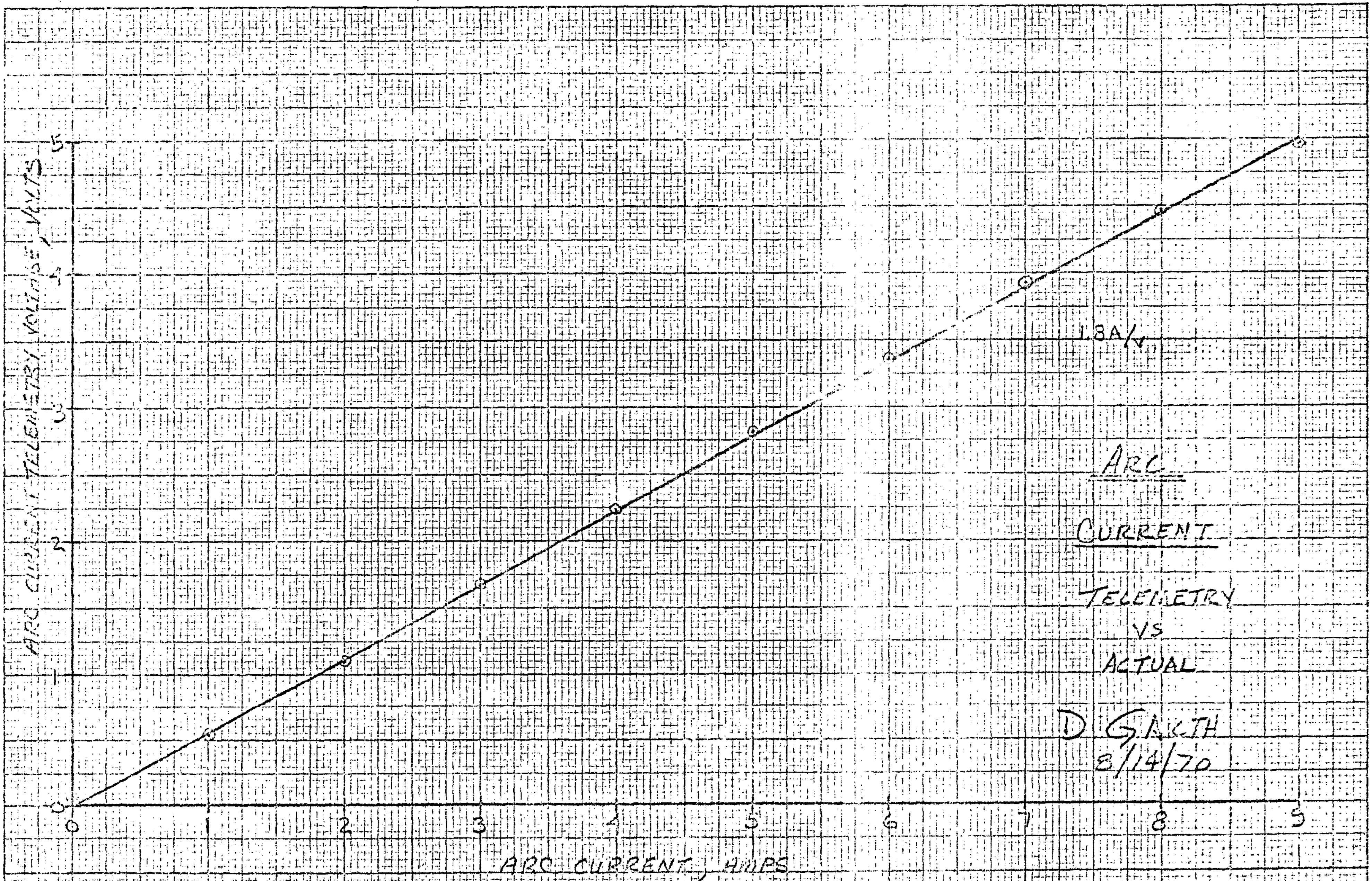


fig 6

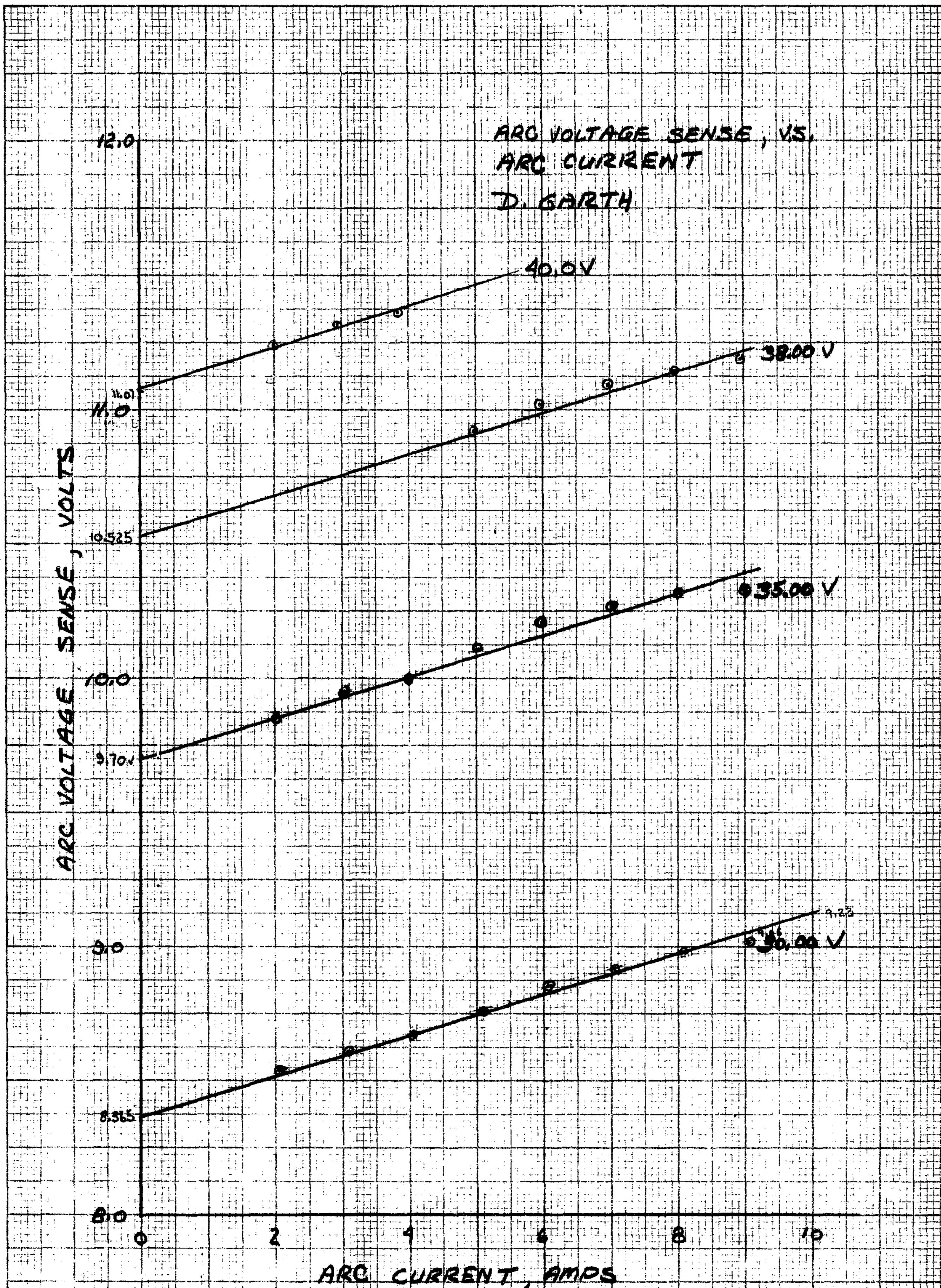


FIG 7

KE 10 X 10 TO ½ INCH 46 1320
KEUFFEL & ESSER CO.

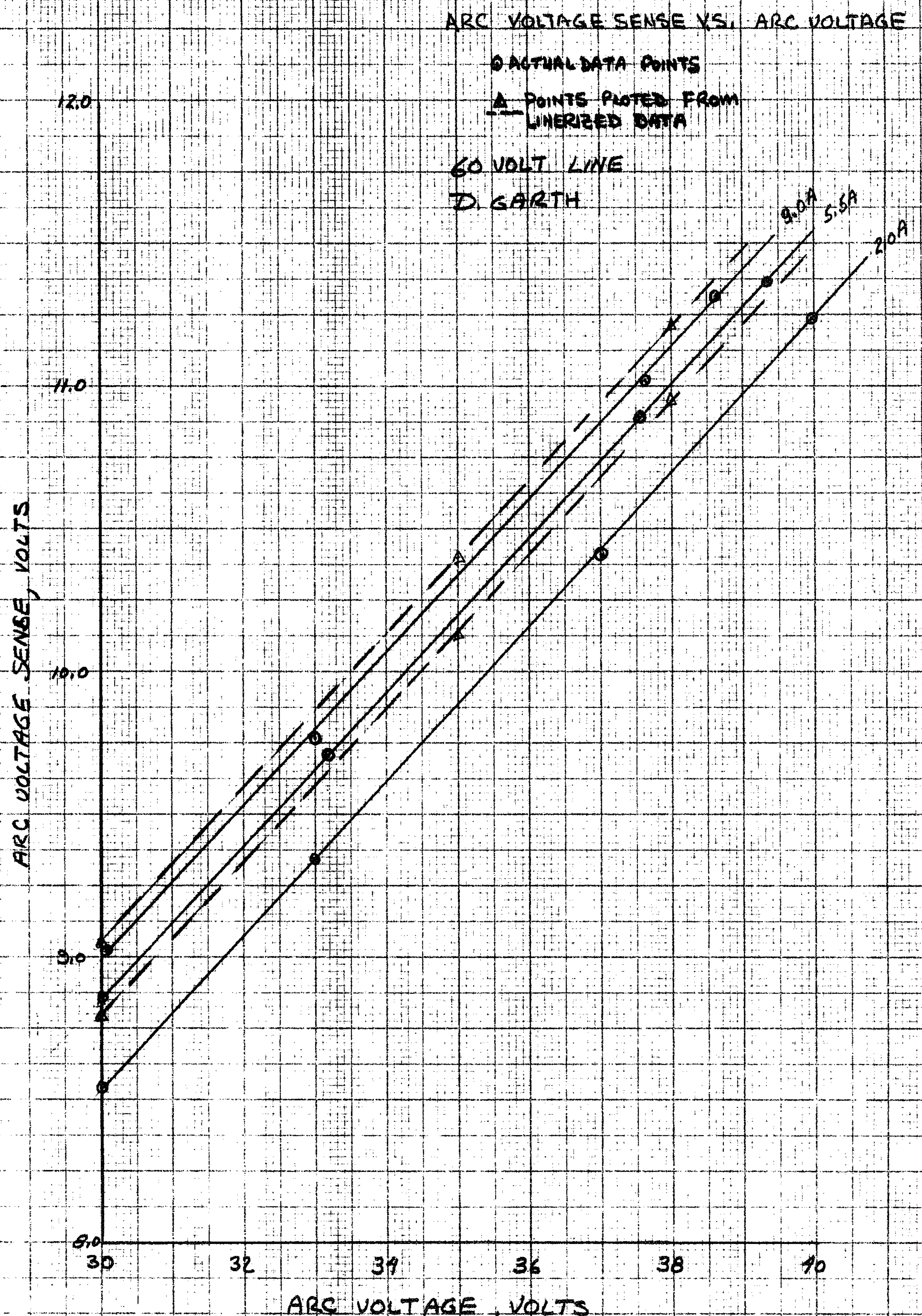

ARC VOLTAGE SENSE VS. ARC VOLTAGE
⊙ ACTUAL DATA POINTS
△ POINTS PLOTED FROM LINERIZED DATA
60 VOLT LINE
D. GARTH
9.0A
5.5A
2.0A
12.0
11.0
10.0
9.0
8.0
30
32
34
36
38
40
ARC VOLTAGE SENSE, VOLTS
ARC VOLTAGE, VOLTS

FIG. 8

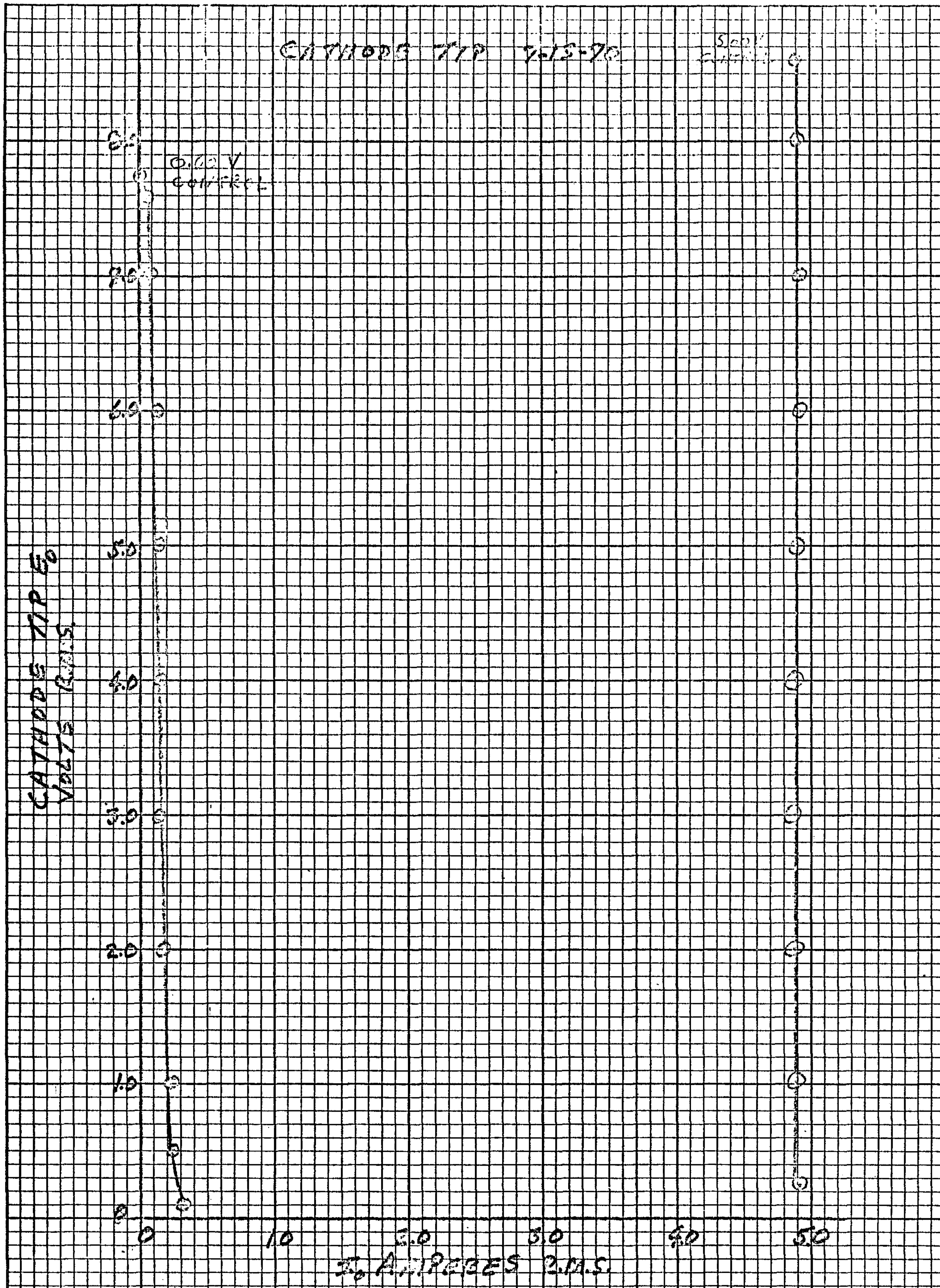

CATHODE TIP 7-15-70
0.00 V CONTROL
CATHODE TIP E0 VOLTS R.M.S.
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0
10
20
30
40
50
I0 AMPERES R.M.S.

FIGURE 9

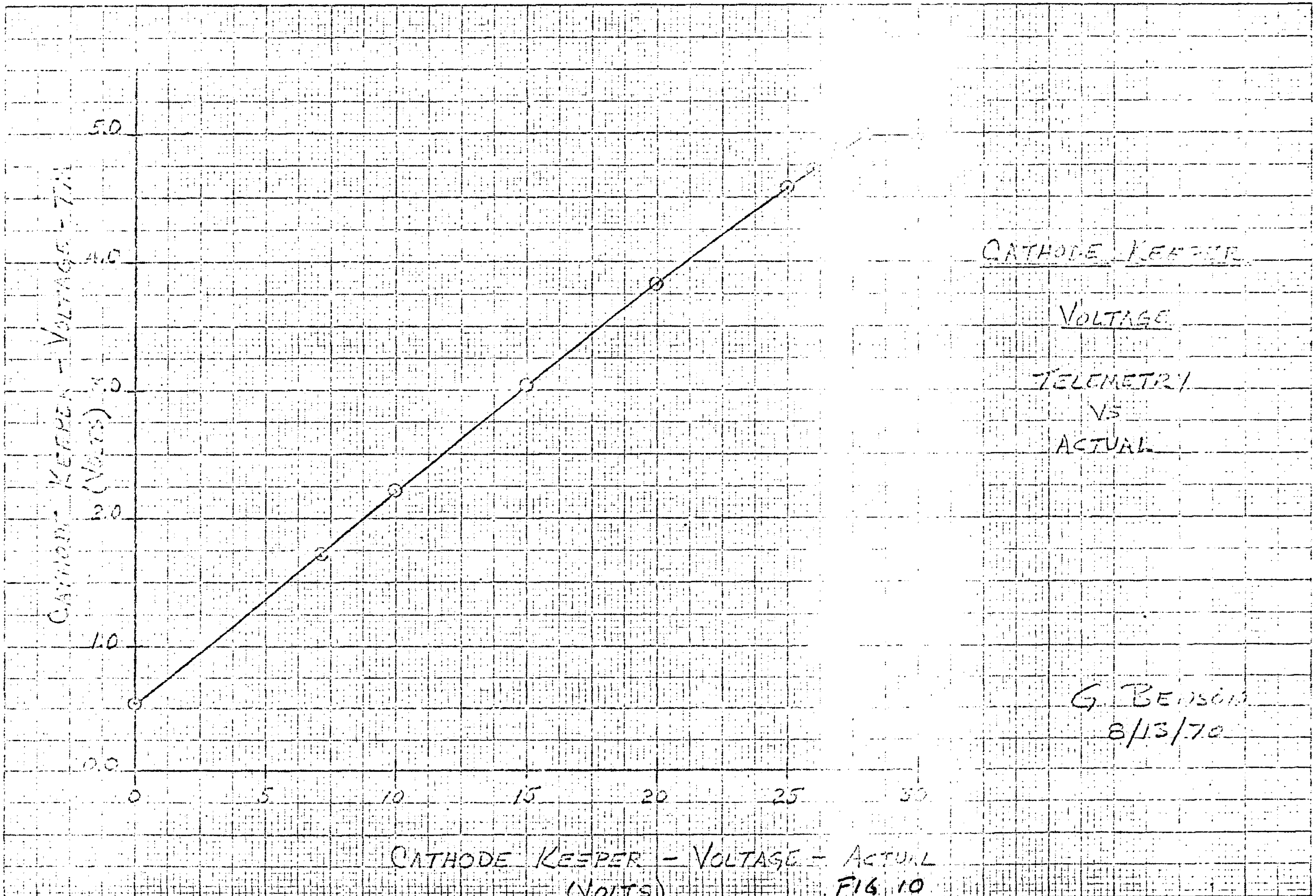

CATHODE KEEPER
VOLTAGE
TELEMETRY
VS
ACTUAL
G. BENSON
8/13/70
CATHODE KEEPER - VOLTAGE - TM
(VOLTS)
5.0
4.0
3.0
2.0
1.0
0.0
0
5
10
15
20
25
30
CATHODE KEEPER - VOLTAGE - ACTUAL
(VOLTS)

FIG 10

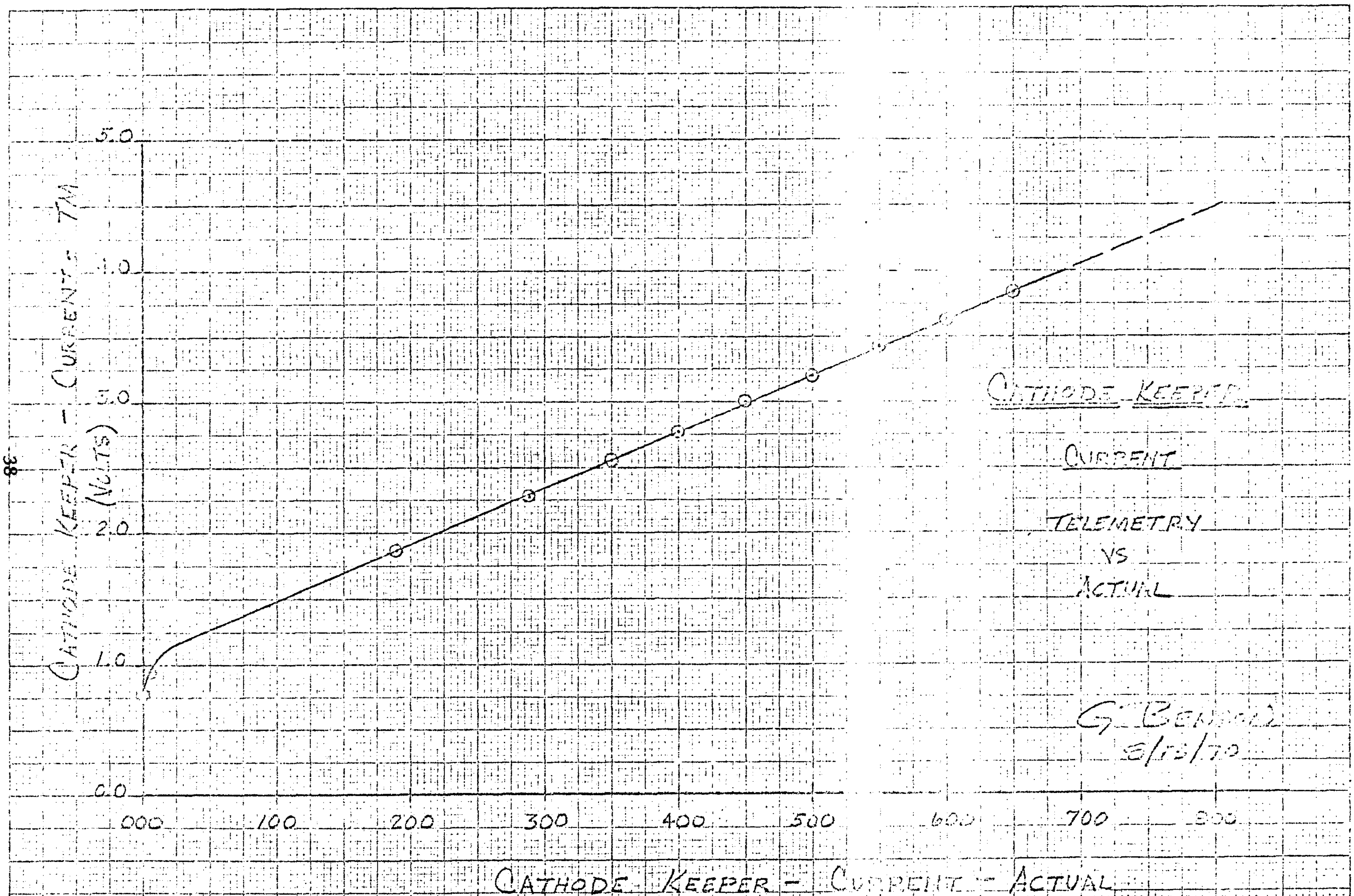

5.0
4.0
3.0
2.0
1.0
0.0
CATHODE KEEPER - CURRENT - TM
(VOLTS)
000
100
200
300
400
500
600
700
800
CATHODE KEEPER - CURRENT - ACTUAL
(mAMPS)
CATHODE KEEPER
CURRENT
TELEMETRY
VS
ACTUAL
G. BENNETT
8/15/70

FIG. 11

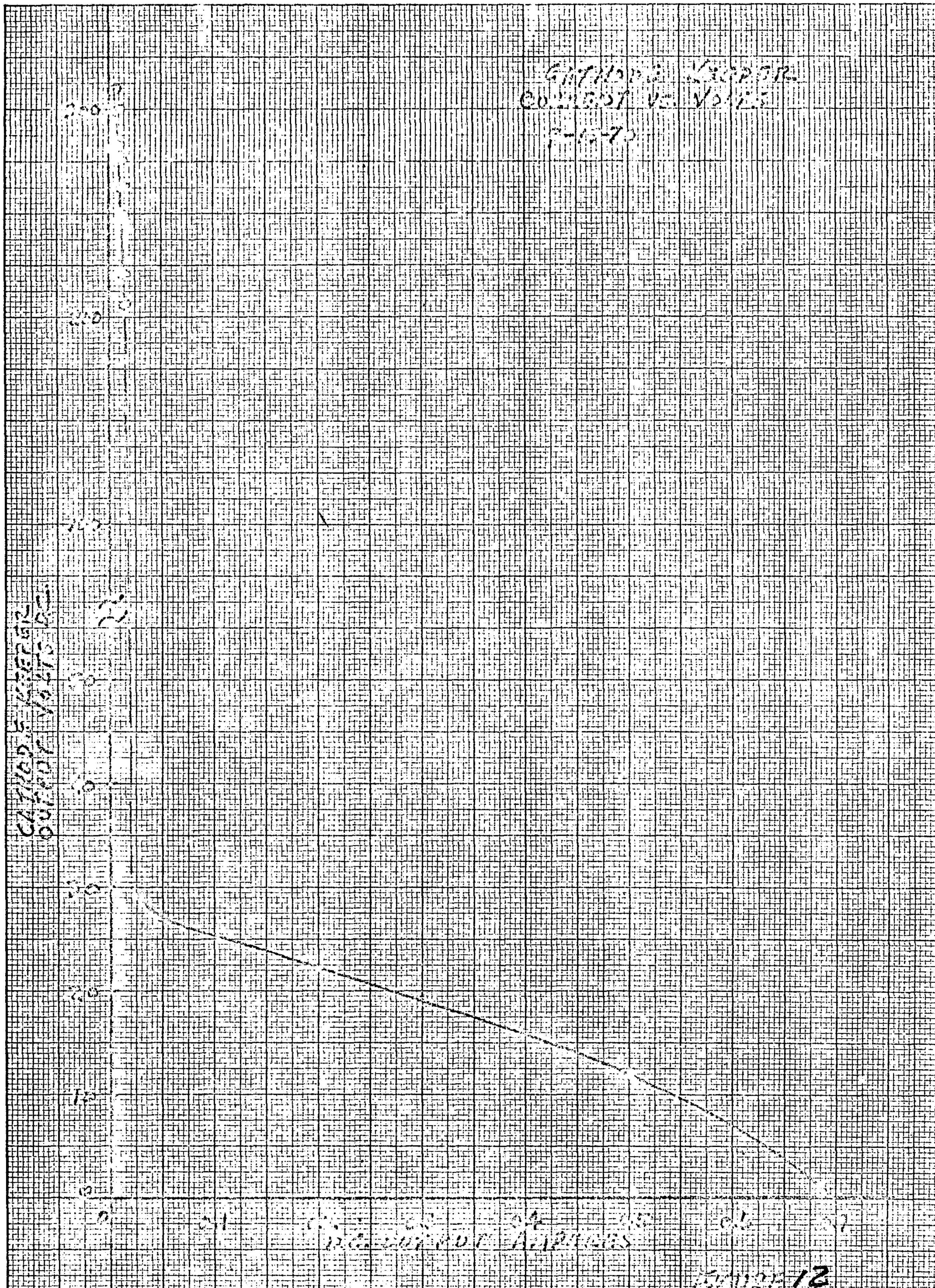
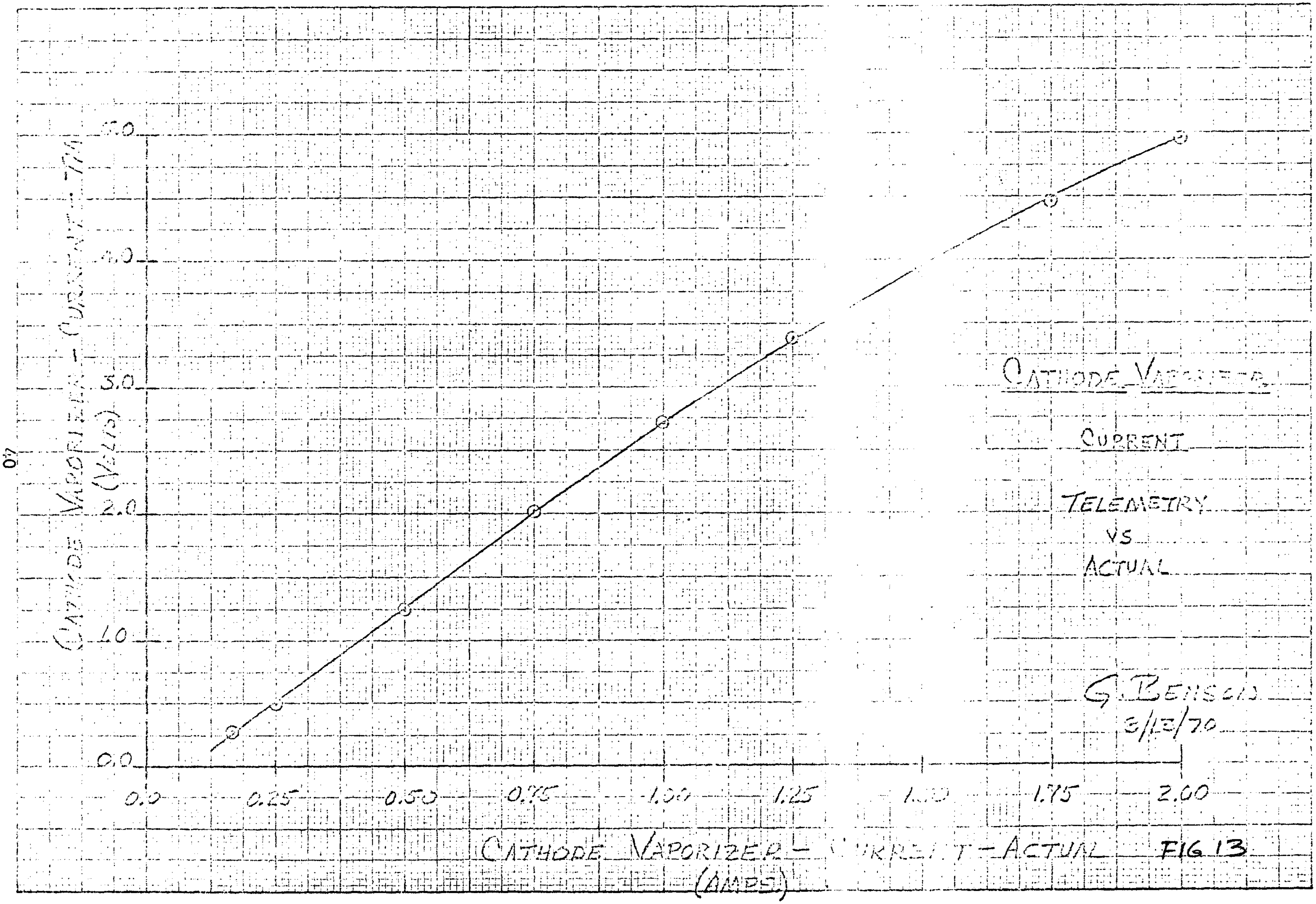


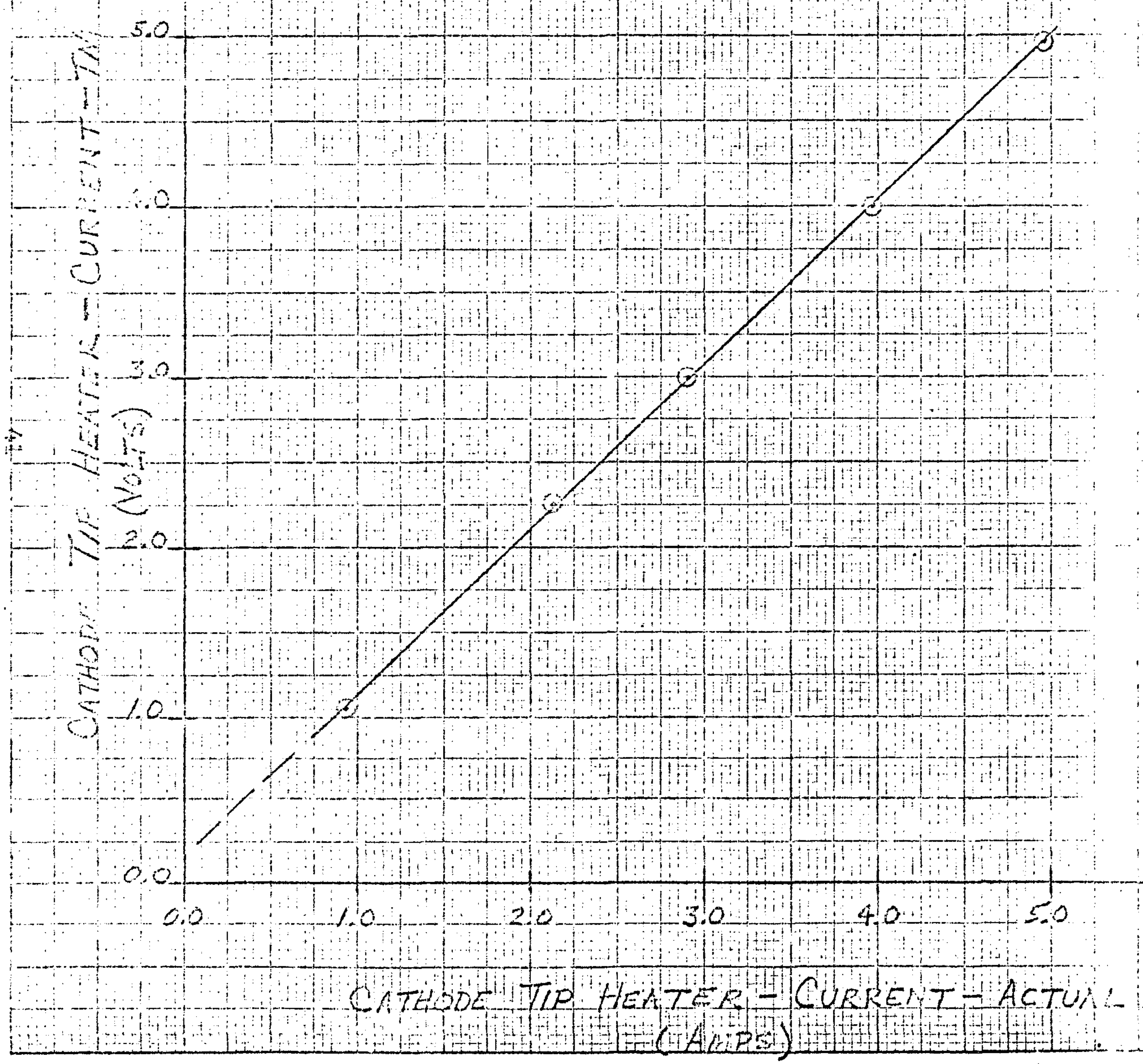
FIGURE 12


CATHODE VAPORIZER
CURRENT
TELEMETRY
VS
ACTUAL
G. BENSON
3/12/70
CATHODE VAPORIZER - CURRENT - TM (VOLTS)
0.0
1.0
2.0
3.0
4.0
5.0
0.0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
CATHODE VAPORIZER - CURRENT - ACTUAL (AMPS)
FIG 13

CATHODE TIP HEATER

CURRENT

TELEMETRY
VS
ACTUAL



G. [illegible]
8/12/70

FIG. 14

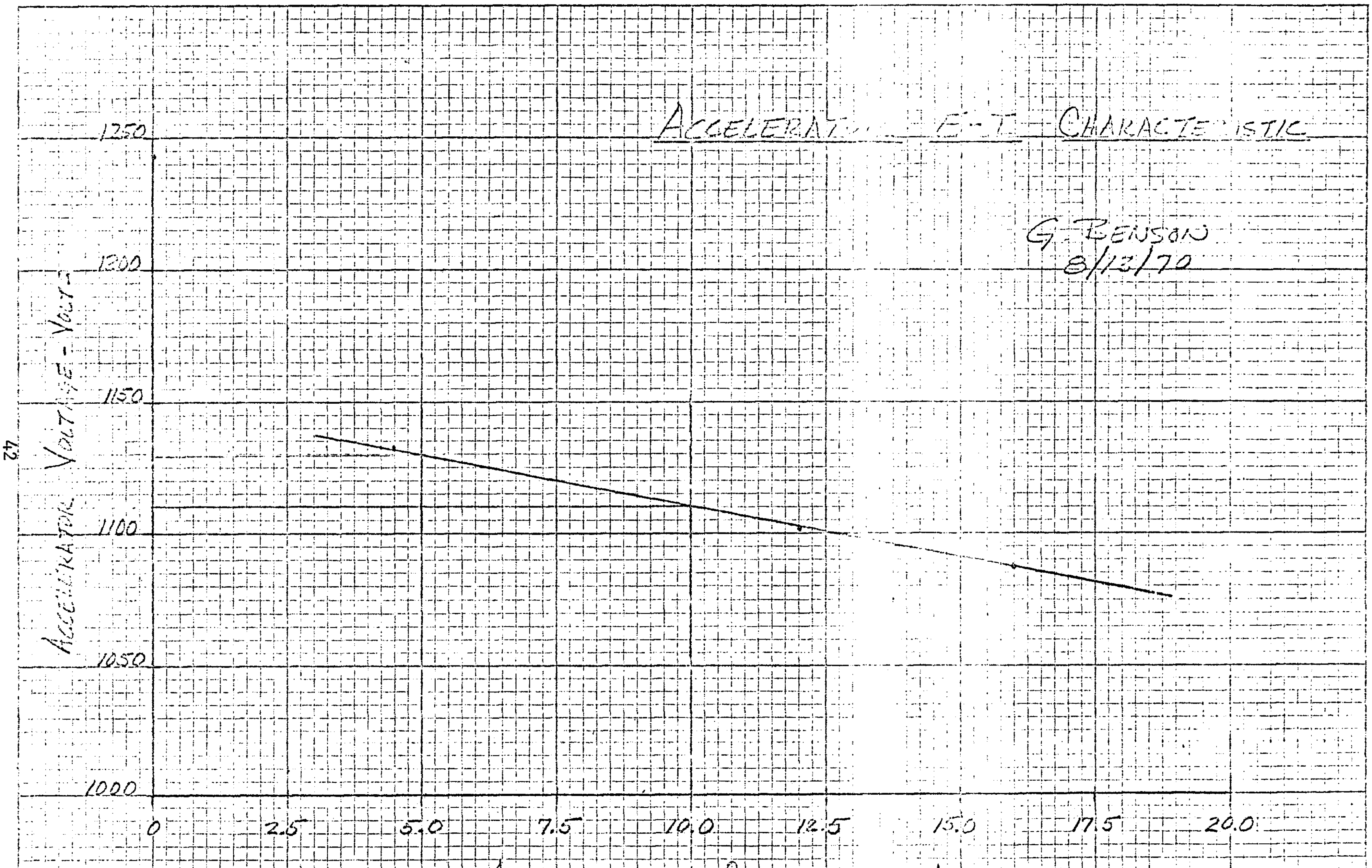

ACCELERAT... E-I CHARACTE...ISTIC
G. BENSON
8/13/70
1250
1200
1150
1100
1050
1000
ACCELERATOR VOLTAGE - VOLTS
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
ACCELERATOR CURRENT - mAmps

figure 15

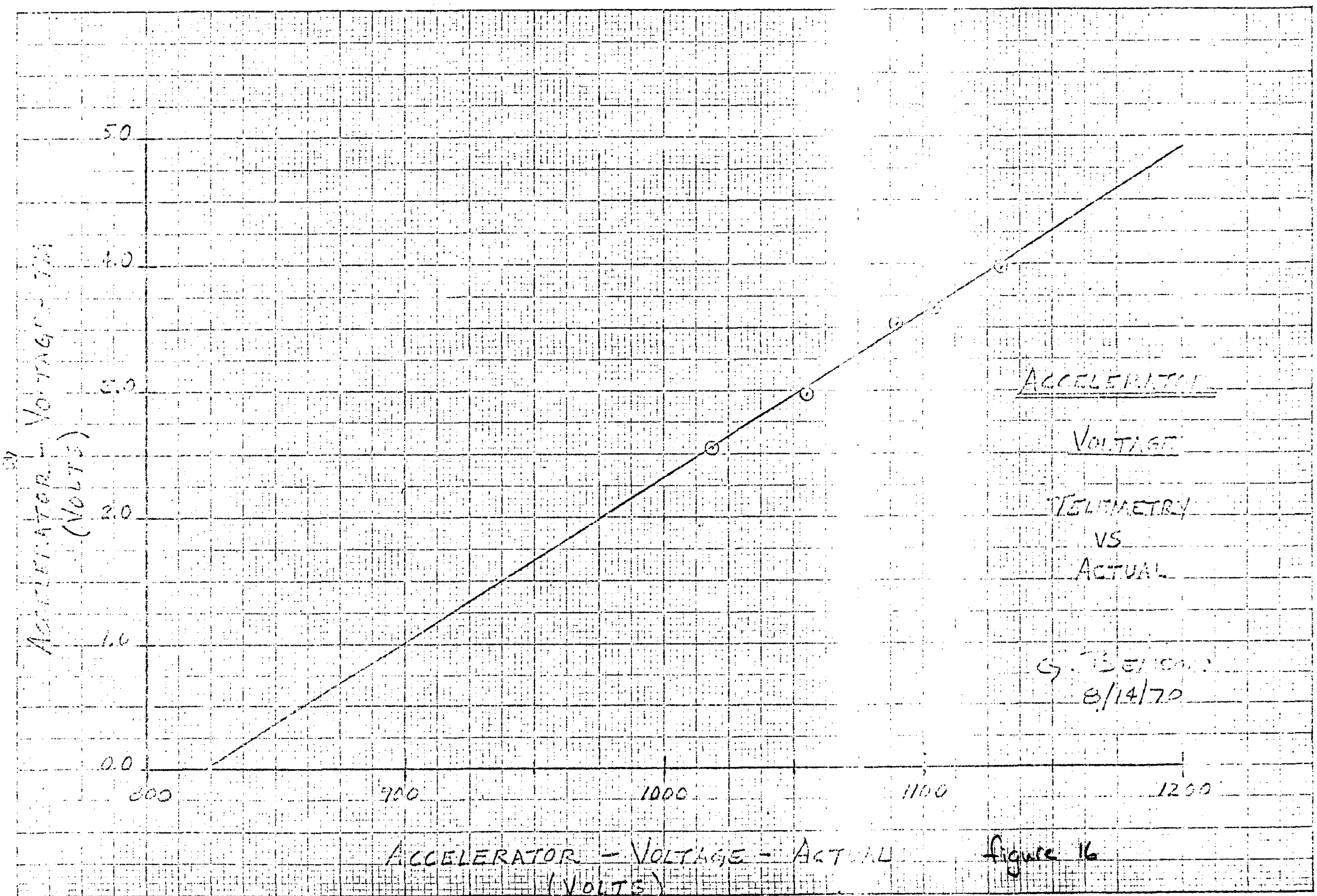
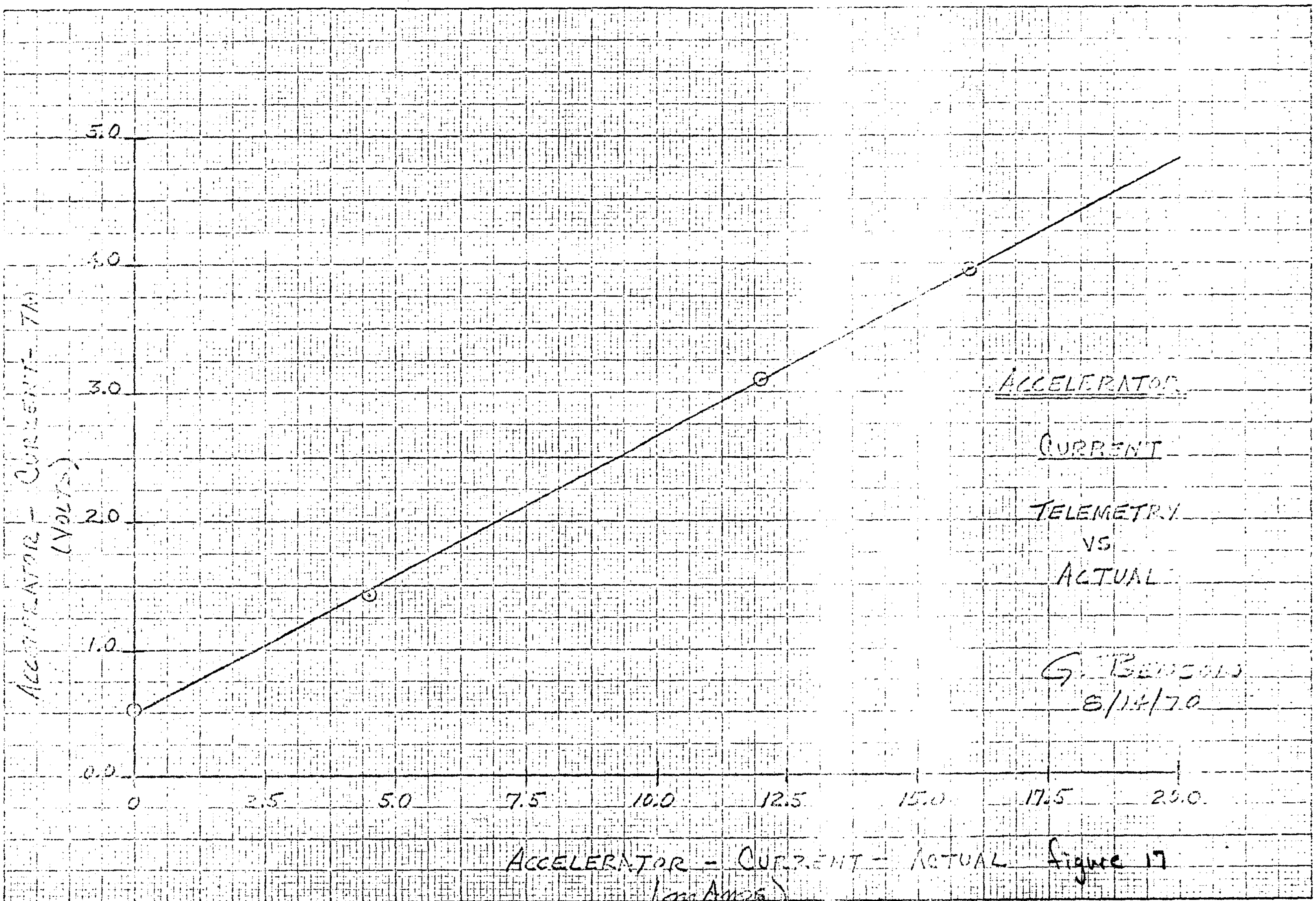

ACCELERATOR
VOLTAGE
TELEMETRY
VS
ACTUAL
8/14/70
5.0
4.0
3.0
2.0
1.0
0.0
800
900
1000
1100
1200
ACCELERATOR - VOLTAGE - ACTUAL
(VOLTS)
(VOLTS)

figure 16


ACCELERATOR
CURRENT
TELEMETRY
VS
ACTUAL
8/14/70
ACCELERATOR - CURRENT - TM
(VOLTS)
0.0
1.0
2.0
3.0
4.0
5.0
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
ACCELERATOR - CURRENT - ACTUAL
(mA)
figure 17